

Chapter 14

Hydrological Variability in South America Below the Tropic of Capricorn (Pampas and Patagonia, Argentina) During the Last 13.0 Ka

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Abstract New limnogeological results (Laguna Mar Chiquita, 30°S) at the middle latitudes in the subtropical Pampean plains of Southern South America are used to establish comparisons with records spanning Late Glacial times and the Holocene covering the Northern Andean Patagonia and the Extra Andean Southern Patagonia. Historical and archaeological data were also used to enlarge existing environmental reconstructions in the central plains of Southern South America. Two groups of climate records – at both sides of the Arid Diagonal- can be distinguished according to their hydrological response during dominant warm or cold climatic phases. The first group includes records from the Pampean region and allows to reconstruct the past activity of the South America Monsoonal System. The second group includes archives of the Patagonian climate, as well as the Salinas del Bebedero, and provides a record of past changes in the strength and latitudinal position of the Southern Westerlies.

Keywords Pampean lakes · Late-Pleistocene/Holocene hydrological reconstruction · Arid Diagonal · South American Monsoon System vs. Westerlies

14.1 Introduction

The reconstruction of Late Pleistocene and Holocene environmental variability across the subtropical Pampean plains of Southern South America (SSA) – i.e., south of the Tropic of Capricorn (i.e., 23° 25'S) and east of the Andes- have been hampered by the paucity of complete and well-dated paleoclimate archives. Despite that the last decade has been marked by a substantial increase of paleoclimatic studies in South America, ongoing paleoenvironmental research clearly shows the

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necessity to analyze past climate variability from a more regional perspective (e.g., LOTRED- SA initiative). To insert the results of single environmental archives in a more regional context is critical to answer some basic and often intriguing questions dealing with the occurrence, timing and frequency of climate fluctuations since the Last Glacial Maximum. The PAGES-sponsored initiative PEP I (Pole Equator Pole through the Americas) represents a milestone using this research strategy (Markgraf et al. 2000, Markgraf 2001) gathering for the first time a limited number of available paleolimnogeological records across the Americas (e.g., Ariztegui et al. 2001, Bradbury et al. 2001, Fritz et al. 2001). Since this early effort a substantial increase in limnogeological studies is shown by the starting of several new research programs (i.e., PALEO-PAMPAS at the middle latitudes or PALATo, PaLaTra, SALSa and the ongoing ICDP-sponsored PASADO in the Argentinean Patagonia).

Results of these investigations point out that SSA climate archives show a complex pattern of timing and climate interactions throughout the Holocene. The precise chronology and magnitude of some of these climatic shifts is still a matter of debate. The new datasets, however, show the advantage of using regional high-resolution multi-proxy climate reconstructions to obtain more realistic past climate scenarios. This downscaling approach is better than the early “smoothed” reconstructions obtained by using paleoenvironmental data at a hemispheric or sub-hemispheric scale. Following this idea, the study of paleoenvironmental records in the Pampean Plains of SSA became critical for comparing latitudinal paleo-circulation dynamics and the hydroclimatic response during the Late Pleistocene and throughout the Holocene. Recent paleoclimate reconstructions show regional contrasting patterns in hydrological responses between the Pampas and Patagonia at both sides of the Arid Diagonal (AD) (Piovano et al. 2006b) (Fig. 14.1). The AD is a narrow band, with precipitation less than 250 mm/year, sited at the boundary or transition between two different atmospheric circulations systems given by the Atlantic and Pacific dominant source of moisture (Bruniard 1982, Schäbitz and Liebricht 1998, Mancini et al. 2005). Numerous paleohydrological reconstructions suggest dominant wet conditions during cold phases -such as those occurred during the middle Holocene or the Little Ice Age (LIA)- in regions located West and South of the AD, like Patagonia or even the Central Andes, with a dominant Pacific source of moisture. For the same climate phase dry conditions can be proposed across the subtropical low-lands east of the AD, under the influence of an Atlantic summer rain regime (Fig. 14.1a). Conversely, extensive dryness across Patagonia and wet conditions in the Pampas can be inferred during warm climate phases such as the Medieval Climatic Anomaly (MCA) or the last part of the 20th century.

In this chapter we present new paleohydrological results at the middle latitudes in the subtropical plains of South America (Laguna Mar Chiquita, 30°S) to further establish comparisons with published limnogeological records spanning Late Glacial times and the Holocene covering the Northern Andean Patagonia and the Extra Andean Southern Patagonia (Fig. 14.1). We also include historical data when available to blend both natural and historically-recorded climate archives in an attempt to enlarge existing environmental reconstructions especially during both the MCA and the LIA in the central plains of Southern South America.

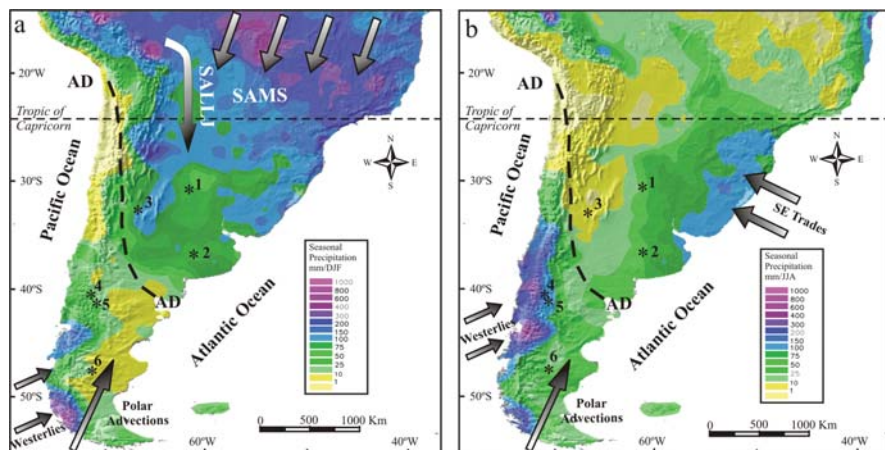


Fig. 14.1 Main components of the seasonal atmospheric circulation patterns in South America (SASM: South American Summer Monsoon, SALLJ: South American Low Level Jets). The numbers refer to the location of the reviewed lakes; (1) Laguna Mar Chiquita; (2) Lagunas Encadenadas del Oeste system (LEO system); (3) Salina del Bebedero; (4) Lago Mascardi; (5) Lago Frías; and (6) Lago Cardiel. AD and dashed-line indicates the position of the Arid Diagonal. (a) Austral summer precipitation (DJF, December-January-February) GPCP Full Data Product Version 4 Gauge-Based Analysis 0.5 degree precipitation for seasonal (DJF) 2001–2002 in mm month. (b) Austral winter precipitation (JJA, June-July-August) GPCP Full Data Product Version 4 Gauge-Based Analysis 0.5 degree precipitation for seasonal (JJA) 2001 in mm month

14.2 Modern Climate of Southern South America

South America climate distribution is closely linked to the particularly tapered shape and topography of the continent combined with the meridional location and height of the Andes, global circulation cells, ocean currents and the proximity of large bodies of water (Cerveny 1998). The source regions for water vapour and dominant circulations in SSA are: (a) the Pacific Ocean and the Westerly circulation belt in Patagonia and Southern Chile; (b) the south-east trade wind circulation associated with the subtropical South Atlantic anticyclone bringing moisture into the subtropics east of the Andes; and (c) meridional transport of water vapour from the humid lowlands of Brazil and Bolivia to the subtropics (Fig. 14.1). A recent overview on present-day South America climate has been summarized by Garreaud et al. (in press).

A major feature of the seasonal climate variability in South America is the development of a monsoon-like system (Vera et al. 2006) which extends southward from the tropical continental region during the austral summer. It connects the tropical Atlantic Inter Tropical Convergence Zone (ITCZ) with the South Atlantic Convergence Zone (SACZ) via large-scale atmospheric circulation containing a low-level jet (Fig. 14.1a). The South American low-level jet (LLJ) starts in the northern part of South America at the foot of the Andes and driven by the Chaco Low provides moisture for South Eastern South America (SESA) (Nogués-Paegle and Mo 1997,

Labraga et al. 2000) and largely determines the hydrological balance of the region (Berbery and Collini 2000, Saulo et al. 2000, Berbery and Barros 2002). Austral summer precipitation maxima (Fig. 14.1a) and dry winters (Fig. 14.1b) characterize a large area east of the Andes between 22°S and 40°S, where the only external sources of water vapour for rainfall are the Atlantic Ocean and the tropical latitudes (Doyle and Barros 2002). Other important climatic features are the episodic incursions of polar air outbreaks east of the Andes (Marengo and Rogers 2001, Garreaud et al. in press) and El Niño teleconnections controlling precipitation and the hydrology of major fluvial systems (Aceituno 1988, Depetris et al. 1996, Silvestri 2004, Boulanger et al. 2005).

The dominant atmospheric feature south of the 40°S is the strong influence of the Westerly circulation belt or Southern Westerlies (SW) largely controlling the precipitation pattern along the Southern Andes (Prohaska 1976, Garreaud et al. in press) (Fig. 14.1). In the Argentinean Patagonia, the west wind zone forms a straight band, with a northern limit running from the Andean valleys in northern Neuquén at about 37°S to the Atlantic Ocean coast at 41°S. Northwards of 37°S the average height of the Andes increases notably (Aconcagua, 6959 masl at 33°S) blocking the effect of the SW and, therefore, the moistured Pacific air. Precipitation over extratropical South America presents a marked asymmetry with wet conditions to the west of the Andes and dry conditions to the east due to the strong rain-shadow effect (Garreaud et al. in press)

As previously mentioned an outstanding climatic and geographic South American feature is the “Arid Diagonal” (Bruniard 1982) corresponding to a narrow band with very low precipitations, typically less than 250 mm/year, that crosses the continent from northern Peru to the northernmost influence of the SW storm tracks at the Patagonian Atlantic coast (Fig. 14.1). In Argentina, this band extends from ca. 40° to 42°S in the Atlantic coast to the north up to 27°S along the eastern flank of the Andes. Regions at both sides of the AD are characterized by different moisture sources: the subtropical summer rain regime towards the north and east (Atlantic influence) while western and south-western areas are mainly dominated by winter precipitation maxima (Pacific influence) (Fig. 14.1). Changes in vegetation and climatic conditions inferred from pollen records allowed to assess the displacement and location of the AD during the mid-Holocene (Mancini et al. 2005).

14.3 Paleoclimate Archives

In this section we examine and compare new and published limnogeological records spanning Late Glacial times and the Holocene south of the Tropic of Capricorn and east of the Andes. The records cover a wide geographical range and climate regimes in the subtropical Pampean plains, the Northern Andean Patagonia and the Extra Andean Southern Patagonia (Fig. 14.1). Historical and archaeological records from the central plains of Argentina were additionally considered to enlarge existing environmental reconstructions corresponding to the last two millennia. Radiocarbon ages from Laguna Mar Chiquita are presented in Table 14.1 while the remaining

Table 14.1 Radiocarbon dates for the core TMC02-2 from Laguna Mar Chiquita

Samples	Depth (cm)	N° laboratory	Material	$\delta^{13}\text{C}/\text{PDB}$ (‰)	^{14}C age year BP	Error	cal ^{14}C AD/BC *a	cal ^{14}C BP *b
TMC02-2-131.5	131.5	Beta-206364	organic sediment	-17.5	1200	40	AD 920-960 (95%) AD 372-612 (98.2%)	1062
TMC-02-161.5	161.5	ETH-26692	bulk sediment	-19.7	1590	60	BC 3034-2561 (98.2%)	1475
TMC-02-181	181.0	ETH-26694	bulk sediment	-24.1	4220	95	BC 11,250-10,940 (95%)	4746
TMC02-2-243.5	243.5	Beta-206365	organic sediment	-21.0	11,100	70		12,938

*a: calibrated ages obtained using Calib rev 5.0.1 (Reimer et al. 2004).

*b: calibrated ages obtained following Bard et al. (1998).

ages were taken from published data and original papers are cited for details. All the cal BP ages (cal ka and cal a) were obtained following Bard et al. (1998). AD radiocarbon ages were obtained using Calib rev 5.0.1 (Reimer et al. 2004).

14.3.1 Subtropical Latitudes: Pampean Plains

Located eastward of the Andes the Pampean plain in Argentina (Fig. 14.1) is a flat and low area with an altitude ranging between 80 and 400 masl and extending to the south up to ca. 40°S. This extensive and geomorphologically very uniform area is characterized by widespread Late Pleistocene-Holocene loess deposits (for a review see Zárata 2003). We have selected Laguna Mar Chiquita (30°S) as a representative paleoclimate record of the northern pampas (Piovano et al. 2002, 2004a,b, 2006b) and the Salinas del Bebedero (33°S) in the SW margin of the plains (González 1994, González and Maidana 1998, García 1999).

Laguna Mar Chiquita (30°54'S-62°51'W) is a shallow saline lake (ca. 10 m maximum water depth) in the subtropical Pampean plains of Argentina (see location in Fig. 14.1) located at the lowermost end of a large catchment area covering ca. 37570 km². Variability in precipitation and river discharge during the 20th century has triggered sharp lake-level fluctuations, making Laguna Mar Chiquita a sensitive hydroclimatic indicator at middle latitudes in South America. The Amazon basin is the principal source of moisture for this portion of South America (Rao et al. 1996) and low-level jets variability largely controls the hydrological balance of the region (e.g., Berri and Inzunza 1993, Nogués-Paegle and Mo 1997, Saulo et al. 2000). Historical and instrumental data show that during dry intervals (i.e., prior to the 1970s), the lake surface was reduced to ~1000 km² whereas covered up to ~6000 km² during periods with a positive hydrological balance (Fig. 14.2a). At present, the lake is at a highstand becoming not only the largest saline lake in South America but also one of the largest in the world. The lake ecosystem, that includes a large wetland in the northern area, is protected by the Ramsar Convention on Wetlands (<http://www.ramsar.org/>).

Well dated short-cores allowed a calibration of the lake sedimentary, isotope and biological response to the last 100 years of documented lake levels changes. The comparison among these sedimentological and geochemical features, their stable isotope compositions, diatom assemblages, pigments and biomarkers shows a coherent picture that further allows us to formulate a well constrained multiproxy model for the basin (Fig. 14.2b,c; Piovano et al. 2002, 2004a,b, Lucatto et al. 2007, Varandas da Silva et al. 2008, Coianiz et al. 2008). The chronology was developed by combining ²¹⁰Pb (Piovano et al. 2002) and ¹⁴C-AMS radiocarbon dating techniques (Table 14.1). The most recent age control based on the concentration of radionuclides ²¹⁰Pb was extrapolated downward up to an evaporitic layer that is present in all the retrieved cores, giving an age of AD 1767. Radiocarbon ages on organic remains (Table 14.1) of longer sedimentary cores allowed the reconstruction of lake-level variations prior to the 18th century, covering regional hydrological changes since the Last Glacial Maximum.

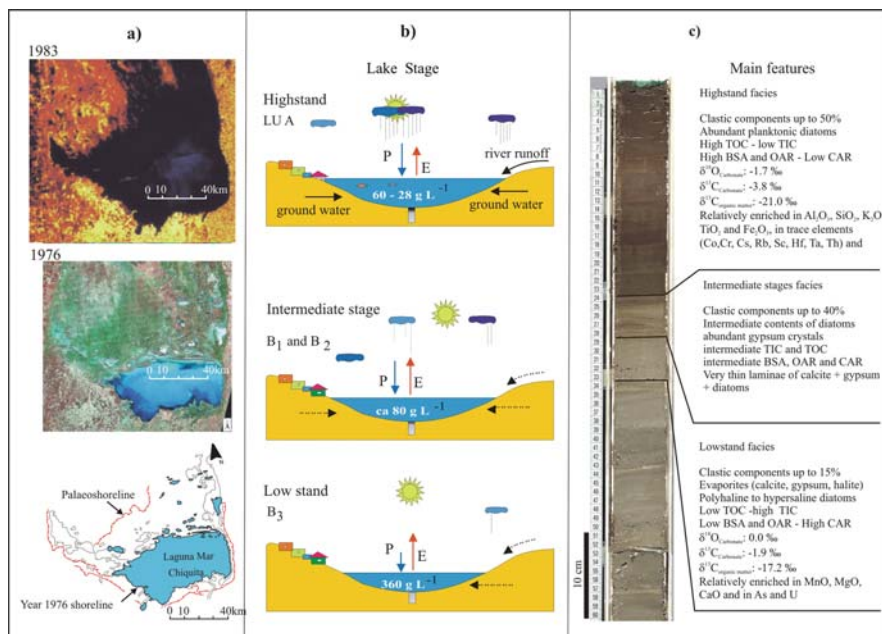


Fig. 14.2 (a) Satellite images showing Laguna Mar Chiquita surface variations between 1976 and 1983 (images from <http://conae.gov.ar>; see Fig. 14.1 for lake location). The scheme on the bottom left shows the extension of the lake (in blue) and paleoshorelines mapped from a 1976 satellite image. The present-day lake shoreline matches the position of the mapped paleoshorelines. (b) Laguna Mar Chiquita hydrological model and associated lake-level changes. P-E arrows represent the precipitation (P) evaporation (E) balance; the relative length of the arrows indicates the predominance of either P or E. Higher river runoff and groundwater inputs are indicated by solid arrows, whereas dotted arrows display comparatively low inputs. Lake water salinity is displayed in g L^{-1} . (c) Sedimentary, isotopical and geochemical datasets for core TMC-00-I showing conspicuous changes during historically documented low, intermediate and highstands (Modified from Piovano et al. 2002, 2004b, Sylvestre et al. in prep.) TOC: total organic carbon, TIC: total inorganic carbon, BSA: bulk sediment accumulation rate, OAR: organic accumulation rate, CAR: carbonate accumulation rate, REE: rare earth elements. Isotope ratios are average values

A semi-quantitative estimation of paleolake-levels using the carbon isotope composition of organic matter as a hydrological proxy (see Piovano et al. 2004a) shows a pattern of alternating lake highstands and lowstands during the past ca. 13.0 cal ka of reconstructed variability (Fig. 14.3). This reconstruction was further confirmed by modelling variations in bulk sediments elemental composition using ultra high resolution μXRF (Lucatto et al. 2007). The limnogeological record of closed lakes, like Laguna Mar Chiquita, usually contains a clear signature of past variations in the regional hydrological balance but they frequently enclose hiatus due to subaerial lake-floor exposures during pronounced droughts. The analyzed hydroclimatic record of Laguna Mar Chiquita indicates the onset of a highstand and therefore a positive hydrological balance at ca. 13.0 cal ka BP (at level 243.5 cm, Fig. 14.3). This early wet phase follows extremely dry conditions recorded by the

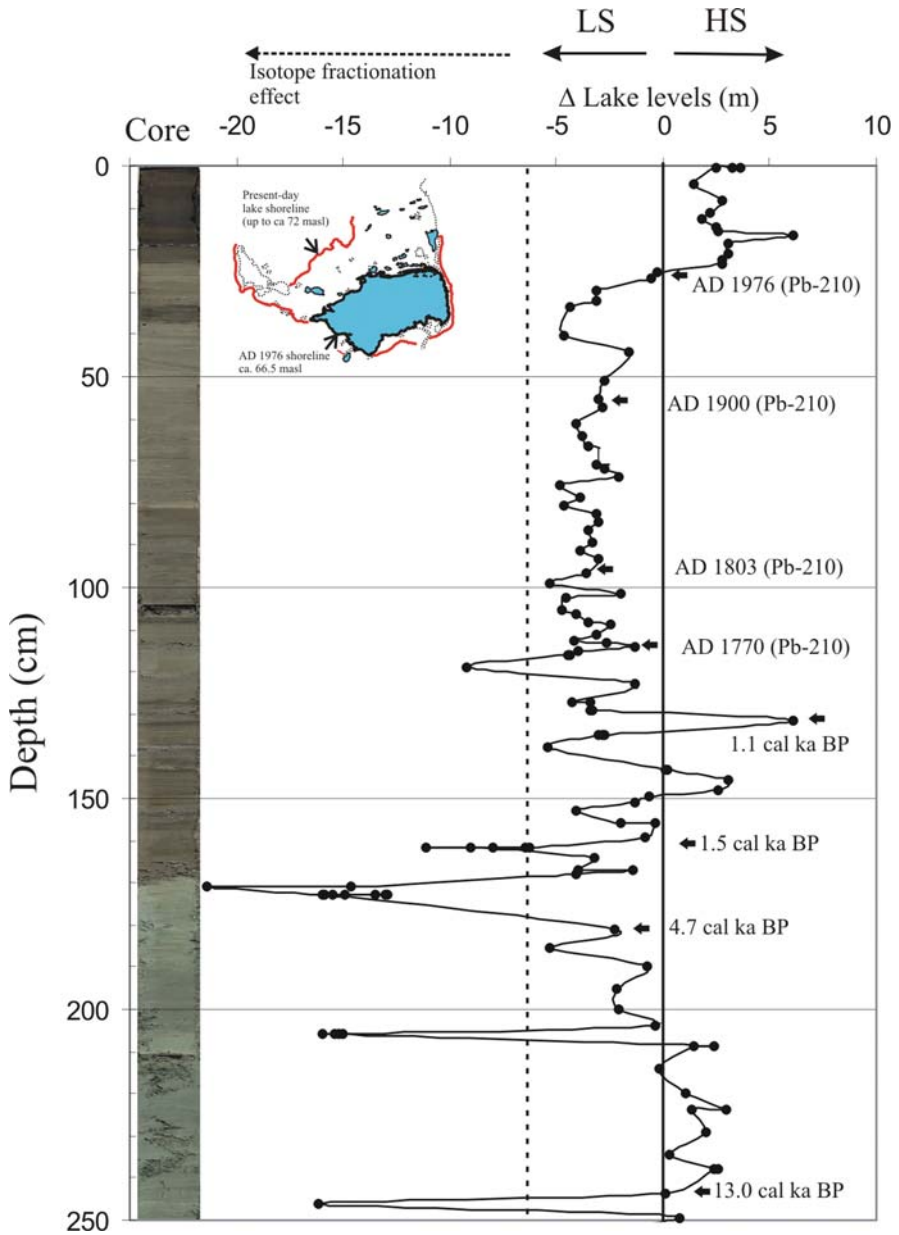


Fig. 14.3 Quantitative paleo-lake level reconstruction based on the isotopic composition of organic matter ($\delta^{13}\text{C}$) on core TMC-02-2 following Piovano et al. (2004a). Photograph of the analyzed core on the left side of the figure. Δ lake level is expressed as a deviation of the 66.5 masl shoreline. Δ lake level = 0 is an intermediate lake-level stage that matches the AD 1976–1977 shoreline elevation (66.5 masl). Positive values represent highstands (lake surface beyond the AD 1976 shoreline position in the scheme) and negative values indicate lowstands (lake surfaces below the

development of discrete levels of evaporates and comparatively more positive isotope composition of both carbonates and organic matter indicating the dominance of evaporation over precipitation throughout the catchment. This wet phase extends along the Early Holocene until a hydrological reversal to an extremely dry phase. Although the age of the onset of this dry phase (level 210 cm, Fig. 14.3) is still unknown, its most intensive magnitude was dated around 4.7 cal Ka BP (level 181 cm, Fig. 14.3). Dry conditions, triggering the precipitation of evaporates and the development of sedimentary hiatuses, were mostly dominant from the Middle Holocene until the middle of the first millennia when less extreme lowstands can be inferred by 1.5 cal Ka BP (AD 372–612; level 161.5 cm, Fig. 14.3) or two highstands, one of them by 1.1 cal Ka BP (AD 920–960; level, 131.5 cm, Fig. 14.3). The timing of the droughts for both the first and second millennia are poorly resolved due to the occurrence of several sedimentary hiatuses indicated by gypsum-halite layers.

In the middle part of the 18th century (~A.D. 1770), sedimentation became more constant and a good chronology has been established for this later part of the sequence based on ^{210}Pb dates (Piovano et al. 2002). The palaeohydrological record indicates dry conditions since ~A.D. 1770 but less extreme than the early part of the sequence with the occurrence of short-lived humid pulses during the second half of the 19th century (A.D. 1850–1870). This lowstand has been associated with the LIA whereas the lake level remained very low until the last quarter of the 20th century.

Salina del Bebedero (33° 20'S, 66° 45'W – 380 masl) is a playa complex located close to the SW margin of the Chaco-Pampean plains (see Fig. 14.1). Past connections of the salina with an inflow fed by Pacific moisture and Andean ice-melt water (Rio Desagüadero fluvial system) triggered highstand phases matching cooling global episodes (González 1994, González and Maidana 1998, García 1999). Today and following the river diversion the salina is only fed by local rainfall with Atlantic provenance and a dominant negative hydrological balance that allows the development of a temporary and very shallow lake with water-depth up to 0.5 m (González 1994).

The presence of paleoshorelines located up to 25 m above the present-day salina floor, in addition to sedimentological features as well as changes in diatom and charophyte assemblages provide clear evidence of recurring lake highstands since the Late Pleistocene until the LIA (González 1994, García 1998, González and Maidana 1998) (Fig. 14.4). Several pulses of lake highstands took place during the Late Pleistocene with the last highstand event dated at 13.5 cal Ka BP (González 1994). This increase in lake level seems to be triggered by local rainfall during a



Fig. 14.3 (continued) AD 1976 shoreline position in the scheme). Cal a BP are calibrated radiocarbon ages (Table 14.1) whereas years AD are derived from the ^{210}Pb chronology (Piovano et al. 2002). Arrows indicate dated level. Lake levels below -6 m are not realistic and are interpreted as a statistical artefact of the equation for reconstruction paleo-lake levels (see Piovano et al. 2004a) due to super heavy organic carbon isotope compositions during high evaporative phases

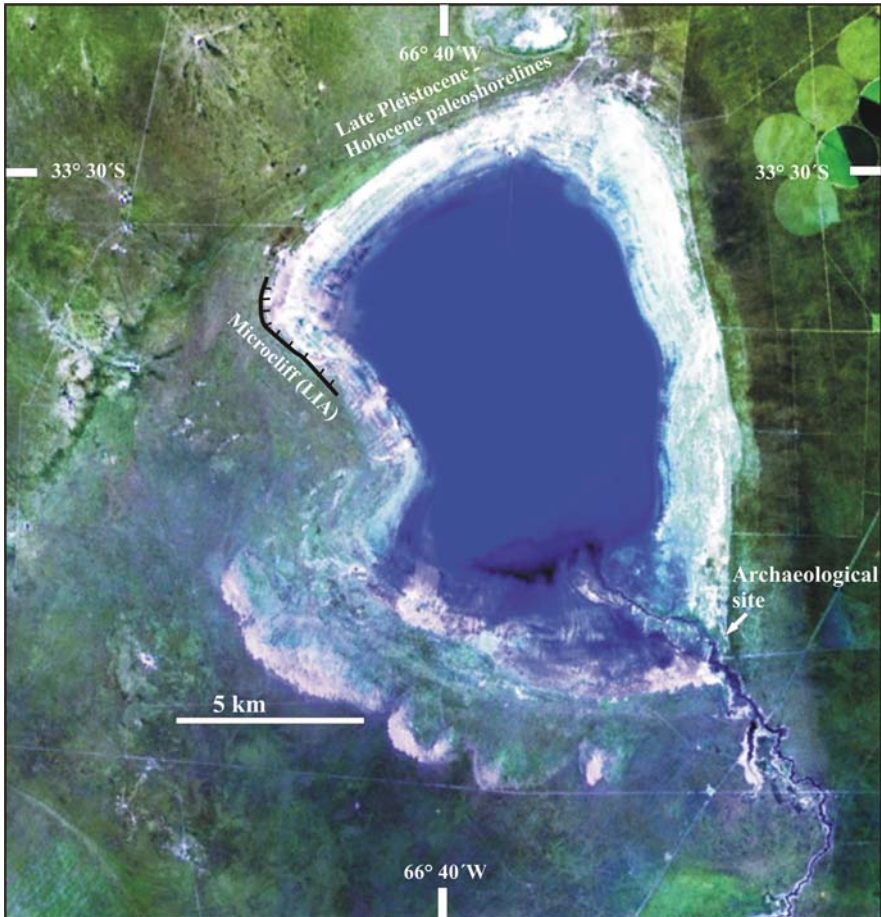


Fig. 14.4 Paleoshorelines at Salina del Bebedero (modified from González and Maidana 1998, see Fig. 14.1 for lake location). Geomorphological evidence of Late Pleistocene and Holocene Lacustrine Stages (in the sense of González 1994, González and Maidana 1998). A paleoshoreline at 6 m above the present-day salina floor (380 masl) is overlapping the archaeological site (indicated in the figure) dated between 10.1 and 9.5 cal Ka BP. The microcliff correspond to the LIA highstands. The satellite image is a Landsat 5–7 processed for agricultural use (obtained at <http://conae.gov.ar>)

warm episode (González and Maidana 1998). Several lacustrine phases, most of them undated yet, took place during the Holocene. The oldest highstand record presents a magnitude of around 6 m above the present-day lake floor and is overlapping an archaeological site dated between 10.1 and 9.5 cal Ka BP (González 1994). Two subsequent highstands (+10 and +6 m over the salar floor) took place during the LIA at 550 and 334 cal a BP, respectively (1280/1420 and AD 1443/1656). The two pulses during the LIA indicate the existence of a dry episode between these two well defined highstands. Historical documents, however, appears to indicate a high

lacustrine stage (+5/+6 m over the salar floor) from the 18th to the 19th century associated to late LIA times (González 1994).

14.3.2 Argentinean Patagonia and Extra-Andean Patagonia

In the southernmost continental portion of South America, the Andes are separated as Cordillera Patagónica Septentrional extending from 39° to 45°S whereas south of 45°S they form the Cordillera Patagónica Austral. East of the Andes Patagónicas Australes (Southern Andes), the Patagonian Plateau or Meseta Patagónica Austral is mainly formed by extended basaltic plateaux.

In recent years there has been a major increase of limnogeological studies across different areas of Patagonia holding multiproxy results and relatively well-resolved chronologies (e.g., Ariztegui et al. 2008). We have selected the following records, (a) Lago Frias (40°S; Ariztegui et al. 2007) and Lago Mascardi (41° S; Ariztegui et al. 1997) in Northern Patagonia; and (b) Lago Cardiel (49°S; Stine and Stine 1990, Gilli et al. 2001, Gilli 2003, Markgraf et al. 2003, Gilli et al. 2005a,b) in the Patagonian Plateau (see lake locations in Fig. 14.1). Other outstanding lacustrine records are Laguna Potrok Aike (52°S) providing continuous multi-millennial sediment records in the dry steppe of southeastern Patagonia (Haberzettl et al. 2005, Zolitschka et al. 2006, Mayr et al. 2007, Haberzettl et al. 2008) and Lago Fagnano (54°S) in Tierra del Fuego (Waldmann et al. 2007, Waldmann et al. in press). Lakes Fagnano and Potrok Aike most probably represent the southernmost continuous continental records outside Antarctica since the Last Glacial Maximum and for the last hundred of thousands years, respectively.

Lago Mascardi (41°S, 71°W; 800 masl) 30 km² and 218 m maximum water depth, is fed directly by turbid glacial melt water from the Tronador ice-cap. Its sedimentary record (Fig. 14.5a) provides a continuous archive of the unstable conditions that characterized the Late Glacial-Holocene transition in northern Patagonia with an unprecedented chronological resolution at this latitude in the eastern side of the Andes. Changes in the sedimentary, geochemical and biological record of this lacustrine basin indicate a sharp stepwise climatic evolution that conflict with early reconstructions suggesting a smooth warming of the region during the transition. Four environmental phases were identified and associated with mass balance variations of the Tronador ice-cap using a multiproxy approach that includes grain-size variations, quantity and quality of the organic fraction, pollen and chironomid remains (Ariztegui et al. 1997, Massaferro and Corley 1998). Between ca. 15.2 and 13.3 cal ka BP there was a climatic amelioration showed by a relative increase in the sedimentary organic matter and grain size, reaching maximum values at ca. 14.5 cal Ka BP. The later indicates a substantial retreat of the Tronador ice-cap in phase with the climatic amelioration that occurred during the Bolling-Alleröd interval in the Northern Hemisphere. A subsequent phase is characterized by small grain size, similar to that observed during the Late Glacial and has been attributed to increasing erosion due to a glacier advance. A sharp decrease in the quality of the

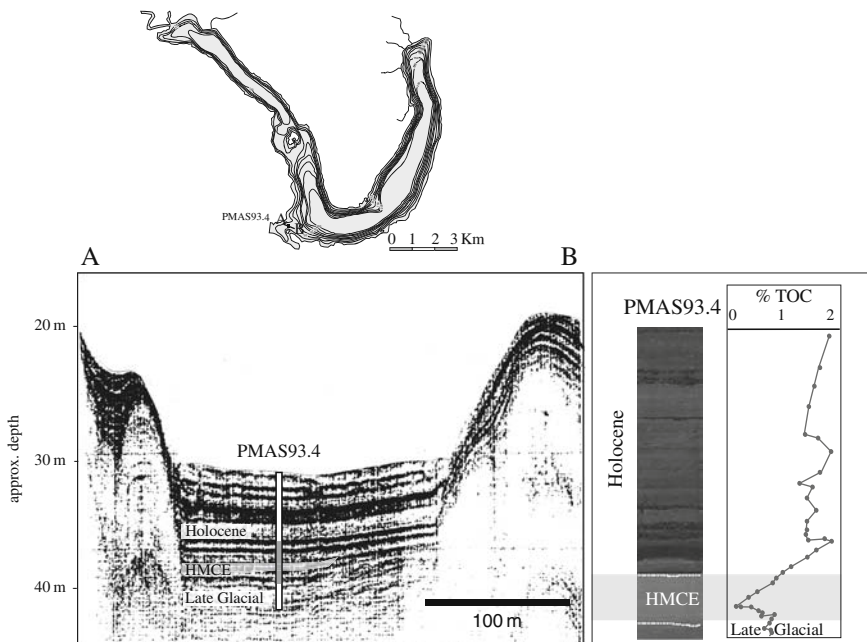


Fig. 14.5 (a) Lago Mascardi bathymetric map and seismic profile showing distinctive seismic facies for both Late Glacial and Holocene sediments (see Fig. 14.1 for lake location). (b) The light gray zone indicates the Huelmo-Mascardi Cold Event (HMCE) that is visualized in core PMA593.4 (located in this seismic section) by both increasing quality of the lamination and total organic carbon content

organic matter and in the pollen influx together with changes in chironomid assemblages point towards a cooling phase. The excellent chronology of these changes and their synchronism with the equivalent Huelmo site in the western side of the Andean Cordillera (Moreno et al. 2001) allowed to define the Huelmo-Mascardi Cold Event (HMCE) that encompass the European Younger Dryas chronozone and the Gerzensee/Killamey oscillation and intervening warm spell (Hajdas et al. 2003) (Fig. 14.5b). The early Holocene in Lago Mascardi is marked by warming temperatures and further retreating ice showed by a grain size increase which is considered to reflect a retreat of the Tronador ice-cap during the early Holocene. The climate record corresponding to the rest of the Holocene shows an increasing trend in the abundance of chironomid, that is affected by both climatic and volcanic forcings (Massferro and Corley 1998). Neither the MCA nor the LIA have been identified so far in this record due to the lack of the appropriated chronological resolution. The nearby Lago Frías record, however, contains a detailed archive of the most recent climate fluctuations in Northern Patagonia.

Lago Frías (40°S, 71°W, 790 masl) is an elongated proglacial lake (4.1 km long, 1.1 km wide; 75 m max. water-depth) located at ca. 7.5 km north of the Frías glacier, one of the Argentinean tongues of the Tronador ice cap (Fig. 14.6). This lacustrine

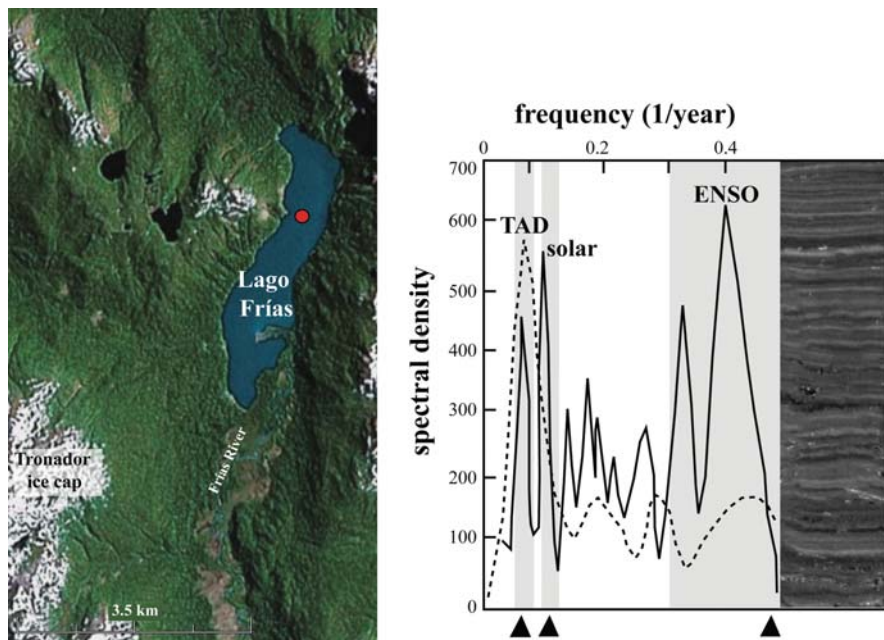


Fig. 14.6 Satellite image showing the location of Lago Frías and the Tronador ice cap. The statistical analyses of annually deposited sediments in Lago Frías (see Fig. 14.1 for lake location in South America) indicate a dominant but not exclusive ENSO signal (see text for discussion)

basin contains a pelagic sequence often affected by mass wasting events (Chapron et al. 2006, Ariztegui et al. 2007). Meteorological, historical and dendrochronological data from the Frías valley show a sharp ENSO impact on local climate (Villalba et al. 1990, 1998). Combining instrumental and historical information with event stratigraphy and radioisotopic data in a well-laminated sedimentary core allowed to generate a robust chronology that confirms the annual character of the lamination. Glacier re-advances have been recorded as a better development of sediment lamination. Variations in the thickness of the clay lamina of a continuous laminated sequence have been related to changes in winter precipitation covering the last ~200 years. A change in the quality of the lamination dated at AD 1873 is in concert with the tree-ring derived cold and rainy period ending in AD 1873 previously assigned to the LIA. Substantial variations in precipitation became evident through changes in lamination from the period AD 1873 to 1909. The most recent formation of push-moraines, between AD 1968 and 1977, is shown by an increase in the lamination index what confirms the sensitivity of this record to changes in glacier activity. Statistical analyses of this dataset indicate an ENSO signal that plays a dominant role in the development of the lamination (Ariztegui et al. 2007). This signal was previously identified in the Frías valley using tree-rings (Villalba et al. 1990 and 1998) and more recently in the sedimentary sequence of Lago Puyehue on the Chilean side

of the Andes (Boës and Fagel 2008). Dendrochronological studies allowed matching cold intervals with higher rainfall and, thus, glacial re-advances (Villalba et al. 1990) that are also recorded through a better development of the lamination along the lacustrine record (Ariztegui et al. 2007). The Lago Frías laminated sequence shows additional frequencies superimposed on the decadal ENSO variations that can be related to both, the eleven years solar cycles, and to a less extent the Tropical Atlantic Dipole (TAD; Ariztegui et al. 2007). Thus, the Lago Frías record provides new insights about the complexity of the various forcing mechanisms behind glacier advances during the LIA in Northern Patagonia. It further highlights the role of precipitation that probably ruled the most recent variation of the glacier equilibrium line.

Lago Cardiel (49°S, 71°W, 276 masl) is located in the Extra-Andean Patagonian plateau of Argentina. It is a closed-lake with a maximum water depth of 76 m occupying a tectonic depression of ca. 20 km of diameter (Gilli et al. 2001). At present, this very arid but sensitive rain-shadow area east of the Andes is seasonally influenced by the Southern Westerlies, therefore the lake provides an ideal location to trace changes in their strength and influence on the local sedimentological regime through time (Gilli et al. 2005a, Stine and Stine 1990, Stine 1994).

The multiproxy analyses of sedimentary cores combined with seismic stratigraphy data indicate substantial lake-level changes during the late Pleistocene and Holocene (Gilli et al. 2001, 2005a,b, Markgraf et al. 2003) (Fig. 14.7). A very shallow lake existed during the starting of the deglaciation until the occurrence of a few hundred years desiccation period after 13.2 cal ka BP. The latter resulted in a peaty, gravelly layer that can also be observed in the seismic (Gilli et al. 2005b). A major change in the hydrological balance followed this desiccation phase. This sequence is found throughout the entire basin implying a large lake level rise after ca. 12.6 cal ka BP up to at least the modern lake level. This transgression of almost +80 m occurred very fast within a few hundred years and it was discontinuous. The occurrence of buried beach ridges during this transgression points towards a stepwise character of the lake level rise since only such a mechanism could allow their preservation preventing their erosion by wave action (Gilli et al. 2005b). Subsequently, the lake level receded but never drops significantly below modern level (Gilli et al. 2005a; Markgraf et al. 2003). High sedimentation rates dominate the north-eastern part of the basin permitting the detailed study of laminated sediments covering the last ca. 1800 years with variable degree of development and thickness (Gilli et al. 2005a,b). Variations in magnetic susceptibility and in trace element content indicate increasing influx of iron oxyhydroxides to the basin during summer that appears as a dark lamina (Ariztegui et al. 2004). Image analyses in the laminated sections of the core show a conspicuous frequency of changes that can be attributed to ENSO as a dominating forcing mechanism behind their formation. These changes in lamination thickness have been related to local wind activity which is directly induced to either intensification or weakening of the westerly storm tracks. It further provides an independent proxy for wind intensity confirming previous studies that were based on indicators at a lower time resolution such as seismic stratigraphy, stable isotopes and pollen analysis (Gilli 2003, Gilli et al. 2005b, Markgraf et al. 2003). All these proxies

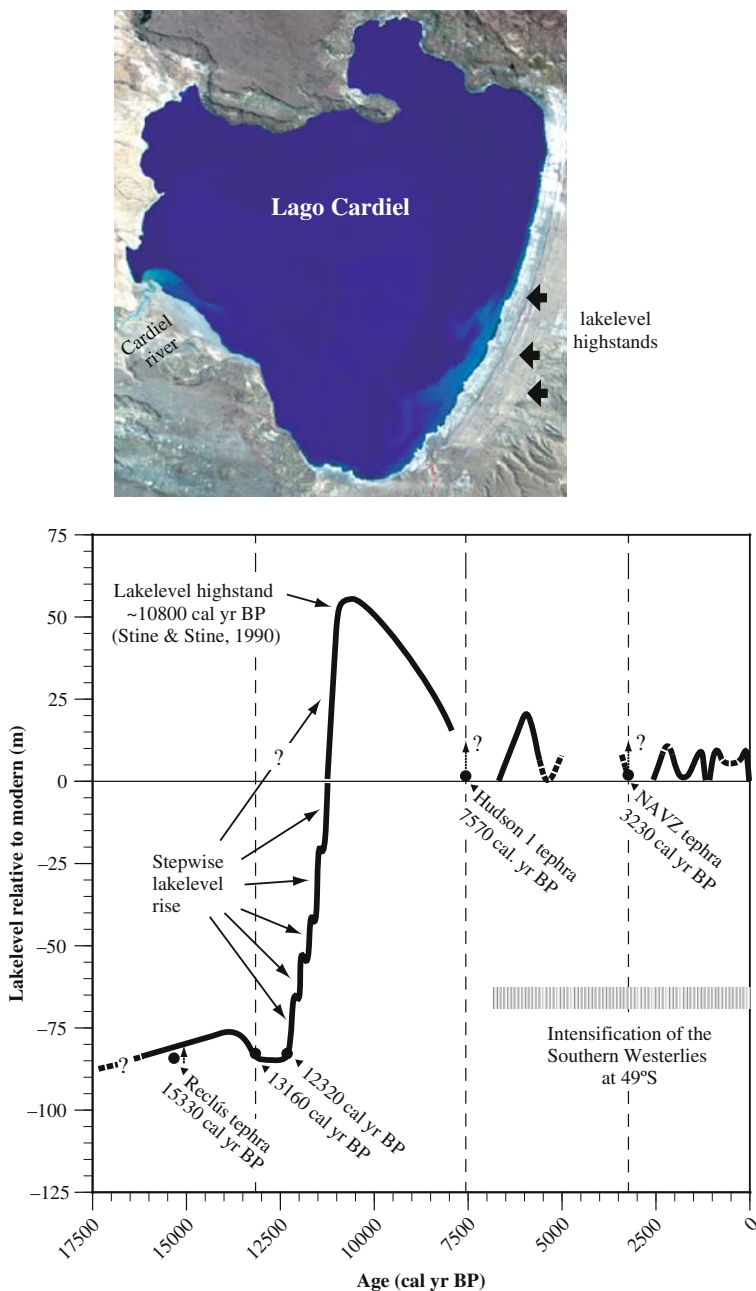


Fig. 14.7 Satellite image of Lago Cardiel in the extra Andean Patagonia and the reconstructed lake level curve using a limnogeological approach (after Gilli et al. 2005a, Ariztegui et al. 2008). See text for discussion

indicate a strong dominance of wind (i.e., precipitation) during the last 2000 years and thus, the thermally defined periods of Medieval Warm Period (MWP) and the Little Ice Age (LIA) are not clearly expressed in the record. Gilli (2003) noticed that the high variability documented in most of the proxies during this interval is a characteristic pattern for many paleoenvironmental records in the circum-South Pacific for the last 3000 years and can be partially explained by an ENSO intensification (Aceituno 1988).

14.3.3 Archeological and Historical Sources of Climate Variability in Central Argentina

The MCA (Stine 1994, Villalba 1994) and the LIA (Villalba 1994, Luckman and Villalba 2001) are very well represented across Patagonia by a wide range of climate archives (i.e., tree-rings, glacial features, archeological sites, paleolimnological records) (Stine 1994, Villalba 1994, Favier-Dubois 2003, 2007, Mauquoy et al. 2004, Haberzettl et al. 2005, Mayr et al. 2005, 2007, Meyer and Wagner 2008, Moy et al. 2008). Conversely, the number of high resolution climate reconstructions across the Pampean plains spanning the last millennium is still scarce. With the exception of the semiquantitative hydrological reconstruction from the Laguna Mar Chiquita (Fig. 14.3) that allows to establish a hydrological comparison between the MCA and LIA, there is a general lack of calibrated hydroclimatic reconstructions to compare the intensity of a certain hydroclimatic phase.

For the period coeval to the MCA several climatic indicators suggest warm and wet conditions for the Pampean plains tentatively between 1400 and 800 a BP with important soil development and formation of swamps in depressions (Carignano 1999, Iriondo 1999). The wet period, particularly between 1410 and 1068 cal a BP, was interrupted by dry-phases as can be recognized in the Laguna Mar Chiquita paleohydrological reconstruction (Fig. 14.3, see level 140 cm). Archaeological sources indicate an increase in the human occupation of this area ca. 1000 a BP, characterized by a mixed subsistence strategy based on hunter-gathering complemented by agriculture, as well as village lifestyle and pottery manufacture, established NW of Mar Chiquita before the Spanish Conquer at about 1573 AD (Laguens and Bonnin in press). During this time, the cultivation line was displaced several kilometers into the present-day playa complex pointing toward more favorable condition for human expansion by 1000 a BP (Laguens and Bonnin 1987, Cioccale 1999). With the exception of the Mar Chiquita paleohydrological reconstruction, no other well dated episodes are available to better constrain the duration of this wet and warm phase during the MCA in center Argentina.

Climate during the LIA in the central region of Argentina was more arid and colder than today (Politis 1984, Cioccale 1999, Iriondo 1999, Piovano et al. 2002, 2004a; Laguens and Bonnin in press). On the loessic plain the hydrological deficit triggered recessions of fluvial and lacustrine systems as become evident through the analysis of Jesuit cartography (Fig. 14.8). Present-day rivers feeding Laguna Mar Chiquita (i.e., río Suquia and Xanaes) infiltrated before reaching the lake, which

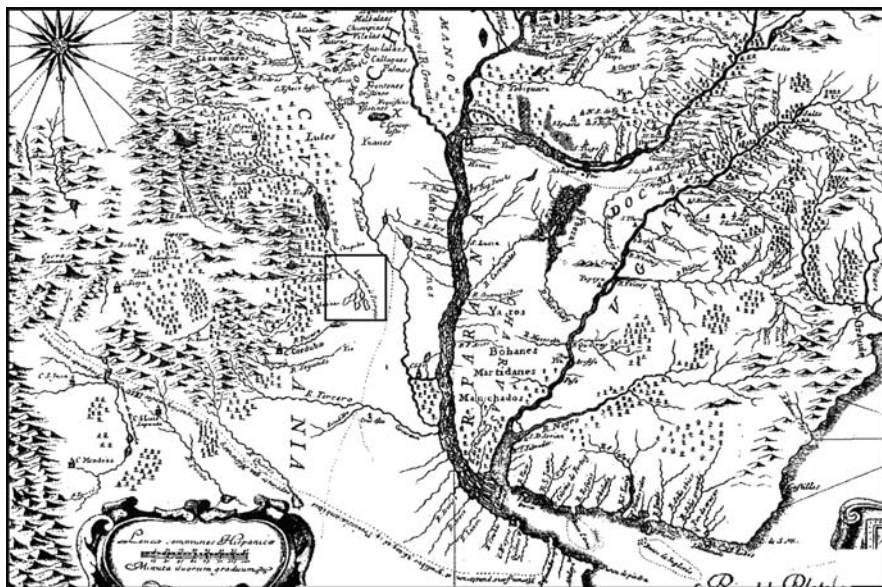


Fig. 14.8 The Jesuit cartography from AD 1732 (taken from Furlong Cardiff 1937) shows a marked reduction in the length of the active channels as well as a decrease or absence of lakes and swamps associated to a dry phase. The square in the center of the map shows that Laguna Mar Chiquita is mapped as small and isolated water bodies (named Laguna de Los Porongos)

was formed by several minor lakes partially covered by dunes (Furlong Cardiff 1937, Parras 1943) instead of a main water body like the present. Archaeological evidences point toward two cold pulses, separated by a comparatively “warmer and wetter” phase during the LIA in the central region of Argentina (Cioccale 1999). The first cold pulse extended from the first decades of the 15th century until the end of the 16th century. Archaeological sources indicate for the 15th century a generalized crisis of the indigenous system that was dramatically increased by the invasion of Spanish conquerors at the end of the 16th century (Laguens and Bonnin in press). This period characterized by high demographic pressure and little development of agricultural practices, coeval with conspicuous environmental changes due to extensive droughts (Laguens and Bonnin 1987, Laguens 1993, Laguens and Bonnin in press). In addition, a widespread record of droughts in the regions north and east of Mar Chiquita (i.e., Tucumán and Santa Fé Provinces) can be reconstructed by the end of the 16th century (Prieto and Jorba 1990, López de Albornoz 1997).

In comparison to central Argentina, the southernmost portion of the subtropics, close to the Lagunas Encadenadas system (37°S; see Fig. 14.1), were under more severe droughts that resulted in frequent dust storms, sand dunes reactivations, desiccated lakes, and pervasive cattle mortality. An interesting archeological-proxy data is provided by the characteristics of the infrastructure for storing food built by

the indigenous (Laguens 1993, Cioccale 1999). The indigenous built underground spaces for food conservation locally named “hornitos”. Two different generations of “hornitos” can be recognized for the period before and after AD 1550. More recent “hornitos” are comparatively bigger than the early ones due to the necessity of increasing the storing capacity. This change is interpreted as a strategy of minimizing risks due to environmental crisis (Laguens 1993).

The intermediate period, spanning from the end of the 16th until the beginning of the 17th century, was characterized by comparatively more positive hydrological balances as suggested by the cartography that shows lake expansions and more defined fluvial systems (Furlong Cardiff 1937). Under this climatic scenario, the Spanish conquer expanded all over the region (Laguens and Bonnin in press). Historical data make references to a general increase in precipitations with a peak between AD 1650–1600 and AD 1720–1740 (Pietro and Jorba 1990). Historical records from the Extinguished Council of Buenos Aires indicate that during the 16th and 17th century the climate was similar to present. Records from AD 1589 to AD 1697 show that 85% of the years were “normal” (Politis 1984).

The second cold pulse started during the first part of the 18th century and lasted until the end or even the middle of the 19th century (Cioccale 1999). This pulse was the coldest and driest part of the LIA. In comparison with the 12th century, the 18th century was characterized by the occurrence of extreme events of droughts or floods for a wide region, according to historical sources (Prieto and Herrera 2001). The Jesuit cartography (Furlong Cardiff 1937) shows a marked reduction in the length of the active channels as well as a decrease or absence of lakes and swamps associated to a dry phase (Fig. 14.8). Historical data also reveal a marked water deficit during the 18th and beginning of the 19th century (Prieto and Jorba 1990). Proceedings of the Extinguished Council of Buenos Aires indicate dryer and cooler conditions than today for the 73% of the years between AD 1698 and 1791 (Politis 1984). Intensive droughts were recorded in the decade of 1770 with a maximum during 1780–1790 in central, west and NW Argentina (Prieto and Herrera 2001).

Extreme and generalized droughts also occurred during the first half of the 19th century from AD 1800 to AD 1810 and from AD 1827 to AD 1832. The last period, namely “the Great Drought” or “Gran Seca”, was very well described by Darwin (1860). In his report Darwin mentioned . . . *During this time so little rain fell, that the vegetation, even to the thistles, failed; the brooks were dried up, and the whole country assumed the appearance of a dusty high-road. Very great numbers of birds, wild animals, cattle, and horses perished from the want of food and water. . . The smaller streams in the Pampas were paved with a breccias of bones. . .* In contrast, the second half of the 19th century, was characterized by an increase of the flood frequency (Moncaut 2003) but always under a dominant negative hydrological balance. Darwin’s descriptions make reference that . . . *subsequently to the drought of 1827 to 1832, a very rainy season followed which caused great floods. Hence it is almost certain that some thousands of the skeletons were buried by the deposits of the very next year. What would be the opinion of a geologist, viewing such an enormous collection of bones, of all kinds of animals and of all ages, thus embedded in one thick earthy mass? Would he not attribute it to a flood having swept over the surface of the land, rather than to the common order of things.*

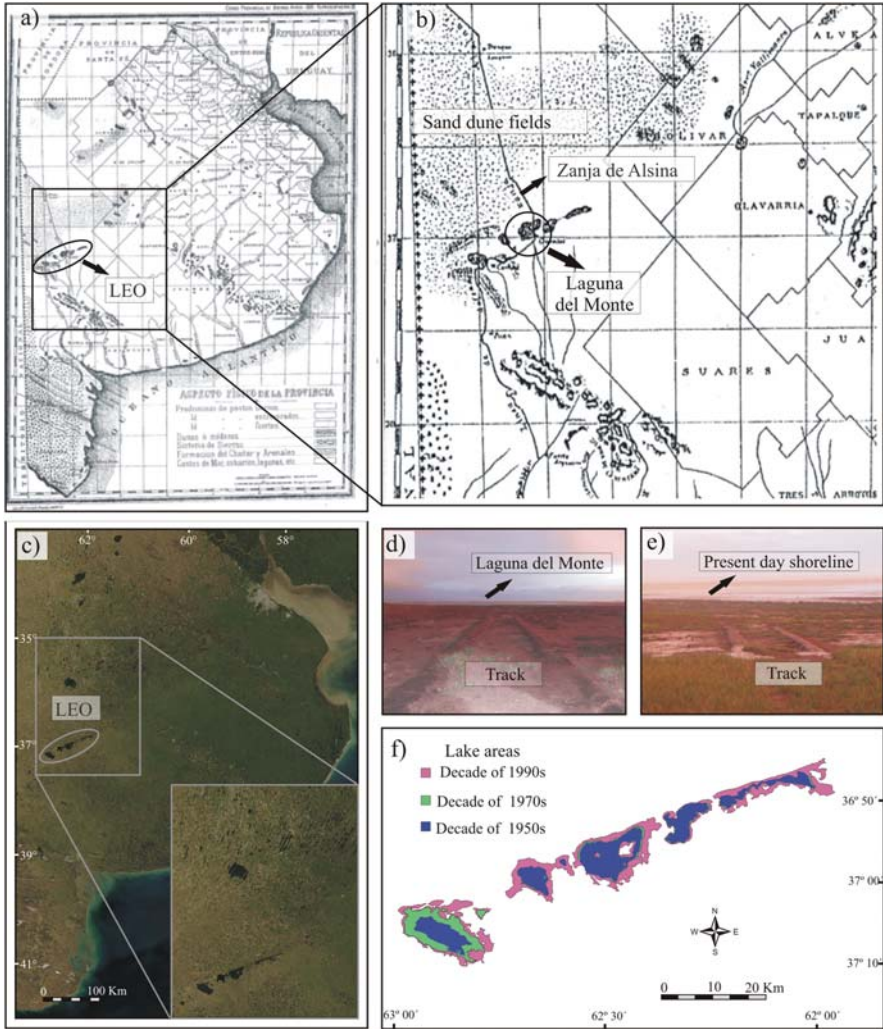


Fig. 14.9 Contrasting hydrological scenario between the end of the LIA and the present-day situation in the Southern Pampean Plain. (a) Historical map of the region from AD 1881 (courtesy of the Museo Regional Dr. Adolfo Alsina). (b) An enlargement of a portion of the map showing a reduced lacustrine system (LEO system) and extensive sand dunes fields. The “Zanja de Alsina” was built as a boundary between Indian domains (to the West) and areas controlled by the Argentinean government (to the East) during the namely “Conquest of the Desert” in 1877. (c) and (d) Photographs showing the remains of a dirty-road running next to the “Zanja Alsina” used to cross the Laguna del Monte during the end of the 19th century. At present the track is interrupted by the most recent lake level increase of Laguna del Monte. (e) Satellite image showing the present-day conditions. (f) Lake area decadal variability of the LEO system during the 20th century

A map from 1881 and a recent satellite image offers a comparison between the contrasting hydrological scenario, during the LIA (Fig. 14.9a,b) and the present-day situation (Fig. 14.9c,d,e,f) in the LEO system, at the southern border of the subtropical plains. The expansion of the sand dune field, reduced lake extensions

and a dirty-road (see “Zanja Alsina” in Fig. 14.9b) crossing a lake was used for travelling across western Buenos Aires Province illustrate the negative hydrological balance during the end of the 19th century. Figures 14.8d,e (AD 2006) shows the old track interrupted by the lake level increase of Laguna del Monte after the 70s (Córdoba et al. 2006).

14.4 Discussion

Limnogeological records south of 30° S in Southern South America show substantial regional hydrological variability since Late Glacial times and overall the Holocene at both sides of the AD. Today, the south-eastern part of the AD (Bruniard 1982) represents the austral border of the subtropics, a very sensitive area to past and present atmospheric circulation changes. It also represents the limit between two main geographical domains in South America: the Pampas and Patagonia. The south-eastern portion of the AD is located along the border of two different circulation systems corresponding to the southernmost influence of the subtropical low-level jet associated to the South America Monsoonal System (SAMS) (Berri and Inzunza 1993, Nogués-Paegle and Mo 1997, Zhou and Lau 1998, Vera et al. 2006) and the northern border of the Southern Westerlies (Prohaska 1976, Garreaud et al. in press) (Fig. 14.1).

Two groups of climate records can be distinguished according to their hydrological response during dominant warm or cold climatic phases. The first group includes records from the Pampean region with the exception of Salina del Bebedero that is mostly controlled by Pacific moisture. This “Pampean group” – with an Atlantic source of moisture – allows to reconstruct the past activity of the SAMS (Piovano et al. 2006b). The second group includes the Salinas del Bebedero and Patagonian climate archives and provides a record of past changes in the strength and latitudinal position of the Southern Westerlies (Markgraf et al. 1992, Gilli et al. 2005a,b, Mayr et al. 2007).

14.4.1 Climatic Driven Hydrological Changes in Southern South America (South of 30°S). From the Late Glacial Times Until the Little Ice Age and the 20th Century

Paleoenvironmental data covering the Last Glacial Maximum show extensive dry conditions for both the Pampas (Muhs and Zárate 2001, Prieto et al. 2004, Piovano et al. 2006b, Zech et al. 2008) and Patagonian region (Ariztegui et al. 1997, Bradbury et al. 2001, Gilli et al. 2001) excepting at Salinas del Bebedero where large amounts of seasonal meltwater from Andean fluvial system triggered high lake levels (González 1994, González and Maidana 1998, García 1999). Model simulations of Last Glacial Maximum westerlies in the subtropics are consistent

with comparatively more humid conditions in agreement with the paleohydrological reconstructions from Salina del Bebedero (Wainer et al. 2005). Following the Last Glacial Maximum extensive dry conditions, the hydrological shift toward positive balances noted in Mar Chiquita and starting by 13.0 cal Ka BP (Fig. 14.3), is also evident through paleoshorelines above the present floor of Salina del Bebedero dated at 13.5 cal Ka BP. This synchronic and in phase hydrological response of both systems (Mar Chiquita and Bebedero) confirm previous assumptions (González and Maidana 1998) pointing toward a precipitation increase with an Atlantic source as the triggering mechanism of the 13.5 cal Ka BP highstand in Bebedero. The duration of the 13.0 cal Ka BP wet and warm phase recorded in Mar Chiquita is still unknown. However, it can probably span the Early Holocene as proposed for different latitudes across the central plains of Argentina (e.g., Zárata et al. 2000, Prieto et al. 2004, Zech et al. 2008). The precipitation and temperature increase covering the Late Glacial-Early Holocene was also identified in the southernmost subtropical region of the Pampean Plains (Zech et al. 2008) suggesting the development of a regional wet phase by a monsoonal circulation strengthening. A climatic amelioration after full-glacial times is further evident at different latitudes in Patagonia as shown in the records of Lago Mascaradi (Ariztegui et al. 1997) and Lago Cardiel (Gilli et al. 2005b), respectively. High lake levels associated to a pluvial phase between 13.2 and 11.8 Ka BP (TL and $^{230}\text{Th}/^{234}\text{U}$ ages) were also proposed for the Extra-Andean Patagonia along 41°S (Tatur et al. 2002) suggesting for this time in-phase conditions for the Pampean region and Patagonia.

The paleohydrological reconstruction in Laguna Mar Chiquita indicates that the wet and warm phase was interrupted by a hydrological reversal to a super-dry phase with an extreme magnitude around 4.7 cal Ka BP. The general drying was dominant until the middle of the first millennia when less extreme lowstands can be inferred (Fig. 14.3). Dry conditions during the Mid Holocene have been widely recognized across the subtropical Pampean plains (Muhs and Zárata 2001, Prieto et al. 2004, Mancini et al. 2005) pointing toward a regional magnitude of the cold and dry climatic event.

The cold and dry Middle Holocene phase is consistent with a reduced latitudinal convey of moisture from the tropics to the subtropics as a consequence of a weakened Monsoonal circulation. The present-day South American Monsoon circulation and austral summer precipitation in SESA are both highly related to changes in the thermal contrast between the continent and the adjacent oceanic regions (Vera et al. 2006). Rainfall variability in a broad region of South Eastern South America is related to both variations in the position of the South Atlantic Convergence Zone (SACZ) and to the sea surface temperature (SST). Colder than usual SST anomalies to the south of the mean SACZ position are also accompanied by lower than usual rainfall in SESA (Barros et al. 2000) and Central-western Argentina (Compagnucci et al. 2002) due to a decrease of low level jet moisture contribution (Doyle and Barros 2002).

Conversely, lake systems fed by dominant Pacific-source moisture (i.e., Bebedero and Patagonian lakes) did not experience the general dry-phase in comparison to those from the Pampean region. The Late-Pleistocene-Holocene transition warming

is recorded both in Lago Mascaradi and Cardiel while the lake levels never dropped significantly during the whole Holocene (Gilli et al. 2001, Markgraf et al. 2003). Hydrological proxies from the Lago Cardiel record indicate an strengthening of the Southern Westerlies after 6.8 cal Ka BP caused by an increase in the temperature gradient as a result of an enhanced influence of the Southeast Pacific anticyclone, larger Antarctic sea-ice extent (Gilli et al. 2005b) and the effect of changes in insolation (Markgraf 1998). The intensified strengthening of the Southern Westerlies after 6.8 cal Ka BP is coeval with weakened Monsoonal circulation in the Subtropics that triggered the Middle Holocene dry period, pointing toward the development of a hydrological anti-phasing at both sides of the Arid Diagonal.

Several climate indicators (lake sediments, historical documents and archaeological data) also indicate the hydrological anti-phasing during the MCA and the LIA. High lake levels in Mar Chiquita after 1475 cal a BP and by 1060 cal a BP and archaeological reconstruction indicate wet and warm conditions across the Pampean region for the period prior and synchronous to the MCA (Villalba 1994). Paleohydrological reconstructions indicate that the MCA wet phase had a magnitude equivalent to the present-day one; however, it was not uniform and included a dry, and therefore cooler, phase between 1475 cal a BP and 1060 cal a BP. In contrast, there are multiple evidence of increased aridity during the MCA overall Patagonia as well as all the regions under the influence of latitudinal shifts of the Southern Hemisphere westerlies (Villalba et al. 1990, Favier-Dubois 2003, Jenny et al. 2003, Mauquoy et al. 2004, Haberzettl et al. 2005, Boës and Fagel 2008, Mayr et al. 2007, Meyer and Wagner 2008, Moy et al. 2008).

Paleohydrological proxies for the cold period corresponding to the LIA indicate opposite hydroclimatic conditions in the Pampean region and Patagonia, respectively. Several proxies in the Laguna Mar Chiquita record as well a high number of historical sources signify an intense drying northward the Arid Diagonal due to a diminished meridional transport of moisture into the subtropics. Conversely, high lake levels can be inferred both in Northern and Southern Patagonia (Stine and Stine 1990, Haberzettl et al. 2005, Ariztegui et al. 2007, among others) as well as in the Salina del Bebedero (González 1994, González and Maidana 1998).

Following the scenario of summer precipitation in the subtropics, the lake-levels increase in Lake Mar Chiquita during the MCA can be interpreted as a response to increased summer moisture convergence. Hence, these more humid conditions are the result of increasing low-level jet moisture transport associated with a weaker SACZ seasonal development. In contrast, colder SST anomalies during the LIA were accompanied by lower precipitations due to a decreased low level jet moisture as identified during present-day cold phases (Doyle and Barros 2002). The link between Southern Hemisphere Westerlies variability and precipitation fluctuation in Patagonia for the MCA and LIA can be possibly explained by changes in the extension of the sea ice south of South America (Meyer and Wagner 2008). The dry phase during the MCA is associated with a decreased SHW activity due to a southward shift of the storm track as the result of a decrease in sea ice cover. During the LIA the volume of sea ice increased again and the SHWs shifted further northward increasing precipitation (Meyer and Wagner 2008).

14.4.2 The 20th Century Climate Variability

The 20th century climate variability shows contrasting hydroclimatic patterns at both sides of the AD. The regions located northward of it were affected by long drought intervals throughout the first three quarters of the 20th century followed by a humid phase since the 70s. This most recent wet phase seems to be linked to both long-term trends and El Niño-Southern Oscillation (ENSO) interannual teleconnections (e.g., Boulanger et al. 2005). The wet spell has not finished yet and resulted in a general increase of precipitations and streamflows in the Río de la Plata basin (Genta et al. 1998, Robertson and Mechoso 1998, García and Mechoso 2005, Pasquini and Depetris 2007), central Argentina (Piovano et al. 2004a; Pasquini et al. 2006), and central western Argentina (Compagnucci et al. 2002, Pasquini et al. 2006) triggering a widespread lake level increase across the pampean plains (Piovano et al. 2002, 2004a, 2006a; Córdoba et al. 2006). In contrast, linear trends in regionally-averaged annual and seasonal temperature and precipitation records in northwestern Patagonia (between ca. 38° and 45°S) indicate significant warming and decreasing precipitation over the 20th century (Masiokas et al. 2008). Negative correlation between regional annual streamflow variations and both annual and seasonal precipitation and temperature records over the 1912–2002 period point toward the opposite influence of this variables on river discharges (Masiokas et al. 2008). At a higher fluvial-catchment scale, the hydrological analyses of the rivers draining Patagonia's Atlantic seaboard show a negative trend in some austral summer months (Pasquini and Depetris 2007). A clear warming trend is also evident at southern latitudes from 46° to 55°S that is intensified at higher latitudes (Villalba et al. 2003).

These results suggest the development of anti-phasing hydrological balances when the most recent hydroclimatic scenario of Patagonia is compared to the dominant situation in the Pampean region. The coeval and in phase sequence of the 20th century hydrological variability shown by Laguna Mar Chiquita water-levels, regional instrumental record of precipitation and discharges from large-scale fluvial systems (e.g., Río Paraná; Río Paraguay) highlight that the Mar Chiquita paleoclimatic record can be further extrapolated to a wider region of South Eastern South America east of the Andes (Piovano et al. 2004a, Sylvestre et al. in prep.).

14.5 Final remarks

Paleohydrological changes occurred in the Pampean region after Late Glacial times can be fairly reconstructed from the Laguna Mar Chiquita paleolimnological record (30°S). The matching 20th century hydrological variability between Laguna Mar Chiquita and large-scale fluvial systems (e.g., Río Paraná; Río Paraguay) remarks the value of Laguna Mar Chiquita record for reconstructing past South American Monsoon System activity. Work on progress also shows the potential of the Lagunas Encadenadas del Oeste system (37°S) for recording the hydroclimatic variability in the southernmost influence of the SAMS in the vicinity of the Arid Diagonal.

Instrumental record suggests the development of anti-phasing hydrological balances when the 20th century hydroclimatic scenario of Patagonia is compared to the dominant situation in the Pampean region. Multiproxy paleohydrological reconstructions in Patagonia and the Pampean plains further indicate the development of the anti-phasing hydrological response after the middle Holocene when took place a synchronic intensification of the Southern Westerlies and weakened Monsoonal circulation. The anti-phasing cold/wet vs. cold/dry hydrological conditions at different latitudes reveal that increased rainfall triggered by intensified Westerlies in Patagonia are synchronous with a diminished advection of humidity from the tropics to the subtropics. This results show that paleolimnological studies along the subtropical plains of South America are critical for obtaining more realistic regional reconstructions of past climate variability. The initiative followed by the PALEO-PAMPAS programme will help to disentangle the role of the subtropics as forcing factors of changes in the atmospheric circulation in South America.

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