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Historical climatic extremes as indicators for typical scenarios of Holocene climatic periods in the Pampean plain

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ABSTRACT

The Holocene has been marked by two different climatic periods in the Pampas, one (8.5–3.5 kyr B.P.), characterized by temperatures and precipitation higher than today and the other (3.5–1.4 kyr B.P.) semiarid, generating parabolic dunes. The humid period produced intense pedogenesis down to 40° lat. S and a mobilization of iron oxides to 30° lat. S, which means tropical climate with temperatures above 20 °C and precipitation higher than 2000 mm/yr. Sand deflation and development of parabolic dunes occur under climates with 300–400 mm/yr. This contribution is based on geological and physical proxies. Typical weather scenarios of those climates are sporadically reproduced today during extremely humid or dry periods. On that basis, meteorological parameters of years beyond the thresholds of 2000 and 400 mm/yr were processed. Dry periods were characterized by a large thermal amplitude, frosts and stronger winds, reproducing the continental anticyclonic circulation of the Late Holocene. Humid extremes were warmer than normal (lower thermal amplitude), with rains produced by local convection processes. Typical scenarios with precipitation above 2000 mm/yr are: 21 °C mean temperature (ca. 1 °C higher than the Present record); 27 °C maximal annual temperatures; 16 °C minimal annual temperatures (more than 1 °C higher than the Present); as a consequence, thermal amplitude was smaller than today, virtually without frosts. Characteristic parameters of the Late Holocene were: mean annual precipitation ca. 350 mm/yr; 15 °C mean temperature; 22 °C maximal annual temperatures; 8 °C minimal annual temperatures, showing significative shifts in the dry season (lower than normal); monthly maximal and mean temperatures higher than today. The result is a thermal amplitude larger than today. Probably, higher quantity of frosts per year, stronger winds and lower relative air humidity in comparison with the humid climate extreme, complete the scenario.

1. Introduction

The use of geological and physical indicators in the reconstruction of past environments is as old as Geological Science. This fact is fixed in the classical principle, which states “*The Present is the key of the Past*”. Indicators offered by Sedimentology, and in a lesser degree by Geomorphology, have probably been the more frequent cases. Such data provide a definitive indicator of extreme climate conditions extending beyond of the historical register.

Proxy data with biological bases were developed in the last few decades with remarkable success and today such techniques are extensively applied in climatic reconstructions, particularly for Holocene and Late Pleistocene times. These developments have the important merit of introducing quantitative criteria in paleoclimatic reconstructions through the introduction of transfer functions and analogue matching into interpretation of pollen diagrams, among others. It often results in interesting advances in regional knowledge. However, as is the case in every methodological tool, these techniques are based on some implicit premises and have limitations as well as evident advantages.

The first requirement for applying a transfer function is the true knowledge of the biology and ecology of the involved species, which at Present is reached only in certain regions of the world, e.g. Europe and some areas of North America. On the contrary, knowledge of the biota is modest in most of South America as well as on other continents. That is a problem that could transform ambitious scenarios into true “mine fields”. According to Markgraf (1993), given the still limited understanding of the modern distribution and ecological significance of many of the principal plant taxa of South America as well as the modern relationship between plant frequency and pollen frequency and the modern climate patterns and their variability, any calibration of pollen frequencies in terms of paleoclimatic parameters may lead to unrealistic conclusions.

We propose in this article to re-assume some robust axioms of Geology with global (not just regional) validity, by developing the rationale to quantitative levels. The basic intention, of course, is to

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offer an independent, complementary tool to already existent techniques. The proposal is applied here in the reconstruction of two Holocene climatic periods that occurred in the central plains of Argentina, a region with relatively abundant multiproxy archives. The main goal is to characterize typical scenarios of both Holocene climates, which are sporadically reproduced at Present during extremely humid or dry seasonal, annual or inter-annual periods.

2. Rationale

This contribution is based on proxies with geological and geomorphological (ultimately physical and chemical) principles, which are complementary to the usual proxies applied in Holocene reconstructions that are dominantly biological. The approach proposed here has some evident advantages: the “samples” used are enormous (dune fields, entire loess formations, zonal soil levels), they are of regional-scale occurrence, and are directly linked to primary external forcing factors, such as temperature, precipitation and evapotranspiration.

The fundamental environmental parameters responsible for the occurrence of geological products such as dune fields or zonal soils have been studied since the first decades of the twentieth century in the field as well as in the laboratory (Davis, 1905; Peltier, 1950; Tanner, 1961; Wilson, 1968; Tricard and Cailleux, 1972). At Present their ranks of occurrence are reasonably well-known and accepted among specialists (Summerfield, 1991).

Dunes are sensitive to modifications in the atmospheric parameters, such as wind direction and intensity and changes in precipitation, that affect the evapotranspiration, soil humidity, percentage of vegetation, and mobility of sediment particles. The areas of dunes tend to accentuate the effects of dry and humid phases (Rognon, 1980) and respond rapidly to climatic changes (Gutiérrez Elorza, 2001). Forman et al. (2001) state that the stratigraphic and geomorphic records of eolian dune deposition on the Great Plains of USA provide proxy information on the timing and magnitude of large-scale droughts when landscape conditions were favorable for the movement and accumulation of eolian sand.

Conversely, in a review of the role of pedogenic processes modifying wind-blown dust (loess), Kemp (2001), indicates that significant changes in climate during past soil-forming intervals might have important consequences for the use of paleosols as proxies of past climatic conditions. According to Morrison (1978), the very presence of a paleosol has paleoclimatic significance in that it is taken to indicate a period of warmer and/or moister conditions between cold and/or arid phases of loess accumulation. Quantitative climatic reconstructions from paleosols normally depend on the establishment of climofunctions, mathematical relationships between climatic variables and measured properties of soils forming at the present surface (Catt, 1991). Sarnthein (1978) summarizes that the past 20 kyrs have witnessed tremendous climatic changes, a glacial maximum at about 18 kyr B.P. (with extensive active sand dunes) and a climatic optimum centered on about 6 kyr B.P., which mark extreme situations for the Quaternary.

A concept applied in this paper is that of sedimentological or geomorphological “thresholds”, above (or below) which a process starts (Monastersky, 1994). These thresholds are associated with a high rate of geomorphic activity, which is a dominant element in determining whether a landscape is formed by the prevailing climate (Summerfield, 1991). Some processes depend on the amount of precipitation, for example transport of sand and dust (Wiggs, 1997; Iriondo and Kröhling, 2007). Others, like glacial and nival processes, are basically linked to a temperature threshold. Another group of processes, such as different zonal soils, are produced mainly by a specific combination of temperature and humidity (Catt, 1990, among others). In consequence, the occurrence of some types of sediments and landforms are robust indicators of paleoclimates (Gutiérrez Elorza, 2001; Berta, 2005).

Another basic characteristic of climate at a regional scale is also useful for reconstructions. It is the repetition of synoptic meteorological structures along successive climatic periods in the same region. The crucial parameters in the theory appear to be the length of the cycle, rather than its magnitude, the length of time that positive feedback processes can operate once they are established and the thresholds are crossed (Monastersky, 1994). An example of a structure is the “Pampero” wind, a cold and dry SSW wind which occasionally blows in the region transporting Patagonic air masses into the Pampas and conveying dust clouds; according to the orientation of longitudinal megadunes of the OIS 4 (marine oxygen isotopic stage 4) age, such wind was the dominant synoptic structure during that period (Iriondo, 1999). Another example is the anticyclonic circulation over the Pampas in extremely dry years, a phenomenon dominant in the Late Holocene (Iriondo, 1990a). Climatic changes in the Pampas during the Holocene can be explained by assuming relatively minor shifts in present atmospheric circulation systems. It is assumed that such fluctuations occur at Present at variable intervals.

Hence, it can be supposed with reasonable certainty that climatic parameters not preserved in the sedimentological/geomorphological record have also occurred in coherence with the preserved ones. Some of those parameters, such as relative air humidity, frosts frequency, maximal temperatures, etc., are undoubtedly important in the reconstruction of past environments. A first approach of this rationale was proposed by Iriondo and García (1993). Benn and Evans (1998) suggested that changes in solar radiation provoke significant changes in the atmospheric circulation, oceans and hydrologic cycles. Those changes can produce shifts in the limits of climatic provinces (Iriondo and García, 1993). By using well-known geological and geomorphological indicators, present atmospheric patterns can be used as a baseline for the reconstruction of past climates, at least those of the Holocene and Late Pleistocene.

3. Present climate in the Pampas

The present climate in the Pampas varies from subtropical in the northeast to temperate in the southwest. Adapting a classical system (Strahler, 1997), the eastern area is subtropical humid and sub-humid (warmest month mean over 22 °C); the northwest area belongs to a dry hot steppe with mean annual temperature over 18 °C; the west is a dry and cold steppe with mean annual temperature under 18 °C and the southwestern region of the Pampas is an arid and cold area (Fig. 1). Other classifications based on morphoclimatic zones as defined by mean annual temperature, mean annual precipitation and the relative importance of geomorphic processes can be adapted from Summerfield (1991). Tropical wet–dry climate in the northeastern zone is characterized by a low temperature range (mean annual temperature 12–30 °C), mean annual rainfall between 1000 and 1800 mm, high chemical weathering, moderate/low wind action, udic soils and few night frosts in winter. It has a Brazilian biota and a thick vegetation cover. By contrast, the central portion of the Pampas is a subtropical semiarid zone characterized by mean annual temperature 8–30 °C, mean annual rainfall 300–1000 mm, moderate/low chemical weathering and moderate/high wind action. This central province has a long dry season occurring between March and September. The vegetation cover is more or less continuous and soils are ustic and aridic (Iriondo and García, 1993). The southwestern part is a subtropical arid region having mean annual temperature 5–30 °C, mean annual rainfall 0–300 mm, low chemical weathering and high wind action.

From the point of view of the climate dynamics, the regional pattern reflects the dominance of both Atlantic and Pacific Oceans on the region. Major influences are the South Atlantic Anticyclone which introduces warm and humid winds from the north and northeast and the South Pacific Anticyclone whose air masses arrive cold and dry from the SSW. Meridional movements or air masses are produced, which provoke frontal rains. In addition, the South American Low-Level Jet (SALLJ) is a relevant feature of the warm season low-level circulation and represents a poleward transport of warm and moist air concentrated