An extended network of documentary data from South America and its potential for quantitative precipitation reconstructions back to the 16th century

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[1] In South America (SA) several documentary based climate time series exist, some of them extending back to the 16th century. Most of these records end in the 19th century, and can not be calibrated against instrumental data. Here, we used the newspaper "Los Andes" from Mendoza, Argentina, to extend documentary based indices of Mendoza precipitation and Central Andes snow depth to the late 20th century. A statistical approach to create "pseudo documentary" 20th century data was applied to prolong eight other documentary records. Increased variability of the hydrological cycle in the Central Andes and prevailing periods of wet and dry years in Mendoza suggest that the 20th century is extraordinary in the context of the last 400 years. The final set of extended documentaries explains significant portions of SA precipitation variability in large areas between 20°S and 40°S and can therefore improve the network of annually resolved precipitation proxies. **Citation:** Neukom, R., M. del Rosario Prieto, R. Moyano, J. Luterbacher, C. Pfister, R. Villalba, P. D. Jones, and H. Wanner (2009), An extended network of documentary data from South America and its potential for quantitative precipitation reconstructions back to the 16th century, *Geophys. Res. Lett.*, *36*, L12703, doi:10.1029/2009GL038351.

1. Introduction

[2] South America (SA) is an important region for understanding the climate dynamics of the Southern Hemisphere, as its climate is strongly related to internal modes of variability such as the El Niño Southern Oscillation (ENSO), the Southern Annular Mode and the Pacific Decadal Oscillation [e.g., *Garreaud et al.*, 2009]. However, long instrumental measurements from SA are rare and inhomogeneities complicate the quantification of long term trends and changes in variability and extremes [*Garreaud et al.*, 2009]. Recently, the number of temporally highly resolved records of SA past climate from natural archives such as tree rings [*Boninsegna et al.*, 2009], ice cores [*Vimeux et al.*, 2009] and lake sediments [e.g., *von Gunten et al.*, 2009] has considerably increased. Nevertheless, the network of existing natural proxies still has significant problems and issues [e.g., *Vimeux et al.*, 2009; *Boninsegna et al.*, 2009]: Other seasons than austral summer are sparsely represented and the network is mainly restricted to sites located in or close to the Andes. The number of records as well as (for non tree ring archives) the dating accuracy and temporal resolution decrease considerably when going further back in time than a few centuries [e.g., *Vimeux et al.*, 2009].

[3] Documentary evidence is an important source of information on the climate of the past [*Brazdil et al.*, 2005; *Pfister*, 1995; C. Pfister et al., Documentary evidence as climate proxies, paper presented at the Proxy Uncertainty Workshop, Electric Power Research Institute, Trieste, Italy, 2008] and has great potential to substantially improve the quality and the spatial and temporal completeness of the predictor network in SA [*Prieto and García-Herrera*, 2009]. A difficulty in using documentary evidence for quantitative climate reconstructions is the fact, that many time series do not have sufficient overlap periods with instrumental data to allow a direct calibration [*Brazdil et al.*, 2005; *Dobrovolný et al.*, 2008; Pfister et al., presented paper, 2008]. This problem is the subject of current research, especially in Europe [Pfister et al., presented paper, 2008; *Dobrovolný et al.*, 2008]. In this study, we use reports of the newspaper "Los Andes" from Mendoza, Argentina to extend two existing documentary records of Central Andes snow depth and Mendoza precipitation to the late 20th century. Newspapers are known to have large potential to serve as documentary records for deriving climate time series even though they are not a primary source [*Bradley and Jones*, 1992; *Brazdil et al.*, 2005; *Gallego et al.*, 2008]. *Gallego et al.* [2008] showed that a snowfall frequency series derived from "Los Andes" reports [*Prieto et al.*, 2001a, 2001b], is significantly related to displacements of the jet stream and patterns of geopotential height as well as to ENSO. Several other studies based on instrumental data affirm the strong connection of the hydrological cycle in the Central Andes to ENSO [e.g., *Compagnucci*, 2000; *Haylock et al.*, 2006], which is reflected in the runoff and snow data of this region [e.g., *Compagnucci and Vargas*, 1998; *Masiokas et al.*, 2006]. Hence, long time series from this area do not only give evidence on past climate conditions on local scales, but can also serve for improving reconstructions of large scale climate variability.

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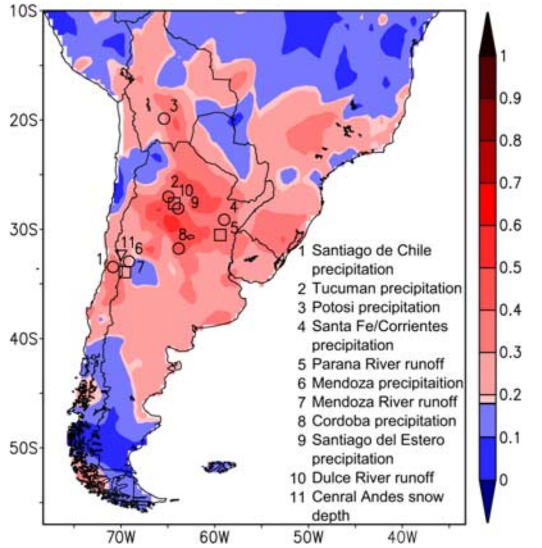

Figure 1. Locations of the documentary records used in this study, indicated by circles (precipitation series), squares (runoff) and a triangle (snow depth). The shading colors represent the fraction of 1901–2006 annual precipitation variance in southern SA that can be explained by the eleven prolonged documentary records using multiple linear regression. Reddish colours stand for grid cells with significant results.

[4] Another possibility to quantify the relation between documentaries and instrumental data is to create "pseudo documentary" time series by degrading the corresponding instrumental data by the addition of a certain amount and structure of noise [*Küttel et al.*, 2007; *Mann and Rutherford*, 2002; *Pauling et al.*, 2003; *Xoplaki et al.*, 2005]. This approach is validated here and then applied to eight other documentary time series of southern SA. Section 2 gives an overview of the data used. In section 3 we present and discuss the methods and results of the extension of documentary data from the Mendoza region using newspaper reports. Based on these results, we apply the "pseudo documentary" approach to the remaining documentaries of southern SA and discuss the outcome in section 4.

2. Data

[5] The documentary records used in this study are eleven precipitation related (i.e., precipitation, runoff and snow depth) index series from SA between 15°S and 35°S (Figure 1, details in Table S1 in the auxiliary material), some of them reaching back to the mid-16th century.[1] We mainly focus on the region of Mendoza, where the newspaper used in this study and three documentary series stem from. Two of them end in the 19th century: Mendoza summer precipitation covering 1600–1806 [*Prieto et al.*, 2000] and Central Andes annual snow depth covering 1760–1889 [*Prieto and García-Herrera*, 2009]. The third series, Mendoza River summer runoff [*Prieto et al.*, 1999] covering 1700–1960, is the only record shown in Figure 1 with an instrumental overlap of sufficient length (52 years). In the 20th century, this series is mainly based on newspaper reports. The snow depth and runoff series are not only influenced by precipitation, but also by temperature [*Prieto et al.*, 1999, 2001b]. For a detailed description of the series we refer to the auxiliary material and to the original references. As corresponding instrumental precipitation data, we used the measurements of the station "Mendoza Observatorio" (source: Servicio Meteorologico Nacional de Argentina) covering 1892–2008. For Central Andes snow depth, we used a maximum snow water equivalent (MSWE) composite time series from six stations covering 1951–2008 [*Masiokas et al.*, 2006; M. Masiokas, personal communication, 2008]. Instrumental Mendoza River runoff data are available from the station "Cacheuta" covering 1909–2000 [*Subsecretaría de Recursos Hídricos de Argentina*, 2004].

[6] As instrumental data to extend the remaining precipitation series in Table S1 (section 4), we used the grid boxes of the new CRU TS3 0.5° × 0.5° 1901–2006 monthly precipitation grid corresponding to the documentary series (Figure 1). For the remaining runoff series we used means of the available stream flow measurements that lay within the catchments represented by the documentary data (Tables S3 and S4).

3. Extending Documentaries by Using Newspaper Reports

[7] Using the newspaper "Los Andes", we derived indexed time series of Mendoza precipitation and Central Andes snow depth for the modern period. We defined the modern period as starting in 1885, when the record of the newspaper "Los Andes" begins. We basically applied the same methodologies as the ones used to derive the indices of the historical period. However, the difference in nature between newspaper records and historical sources required minor adaptations in the chronology development process (see auxiliary material for details). Figure 2 shows the extended precipitation and snow depth series as well as the Mendoza River Runoff record (vertical bars, new data in red) and the corresponding instrumental data (blue lines). The modern precipitation indices show clear decadal fluctuations. The first 15 summers are rather wet, followed by a dry period of four decades. In the early 1940s there is another shift towards wet conditions, which last until the end of the series. The wet trend at the end of the series is also visible in the instrumental data (Figure 2). In the historical series, there are generally less distinct dry or wet periods, except for the clustering of wet years between 1630 and 1685. The modern snow depth series has clearly more years of low snow depth than the historical part, particularly in the first half of the 20th century (Figure 2). This is followed by a period of positive anomalies between 1972 and 1995. In the runoff series, positive and negative values are evenly distributed in both the historical and modern periods. In the periods with instrumental overlap (1892–1985 for precipitation, 1951–1996 for snow depth and 1909–1960 for runoff), the three index series correlate significantly with the corresponding measurements (Table 1). The coefficients

[1] Auxiliary materials are available in the HTML. doi:10.1029/2009GL038351.

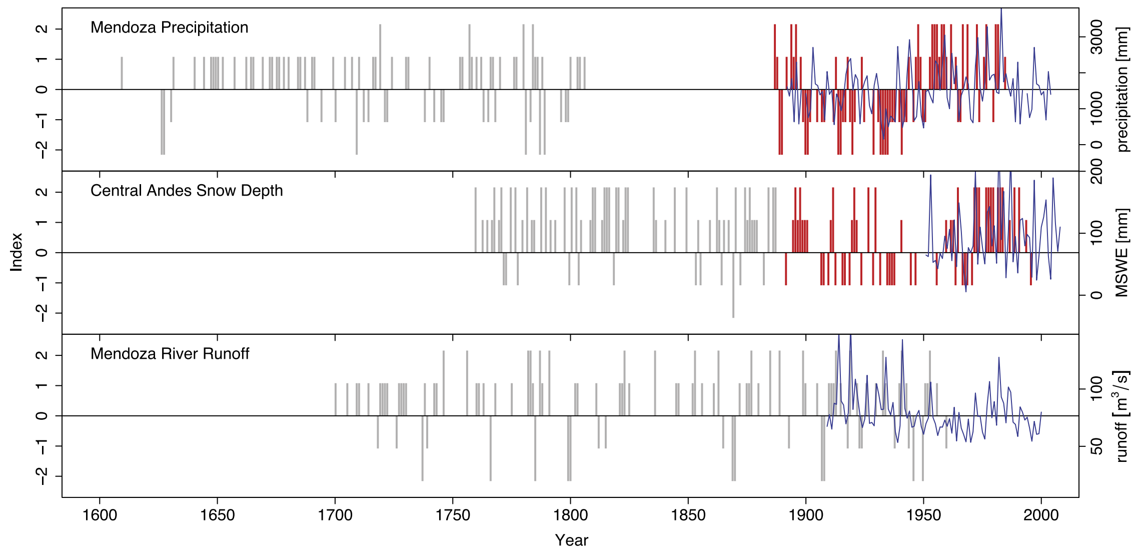

Figure 2. Documentary series with instrumental overlap. Grey bars: Published documentary series. Red bars: New newspaper based indices. Blue lines: Independent instrumental measurements.

are well within the range of "typical" values derived for documentary data, which are of order 0.5 [*Pauling et al.*, 2003; *Rodrigo et al.*, 1999]. The correlations between the three series in the historical and modern period remain similar (Table 1), which suggests that the modern, newspaper based series are suitable to extend the historical data. Table 1 shows that all series have an increase in standard deviation from the historical to the modern period. This may be a reflection of the real conditions or due to changes in the type and amount of information available in the documentary sources. An indication, that the increase in variability is not due to the change in source, is the fact that between 1823 and 1884, where the runoff and snow series are already partly based on newspapers [*Prieto and García-Herrera*, 2009; *Prieto et al.*, 1999], the standard deviations of the snow (0.89) and runoff (0.76) series are at lower levels than in the rest of the historical period (the precipitation series has no data in that interval). *Le Quesne et al.* [2009] find an increased drought probability in the late nineteenth and twentieth centuries in Central Chile, based on tree ring records. Various ENSO reconstructions show evidence for an increased ENSO variability in recent decades as compared to earlier centuries [*D'Arrigo et al.*, 2005; *Mann et al.*, 2000; *Stahle et al.*, 1998]. This supports the evidence that an increased variability of the hydrological cycle in the Central Andes, which is strongly related to Central Chile tree growth [e.g., *Boninsegna et al.*, 2009] and ENSO [e.g., *Compagnucci*, 2000], may be realistic. In order to quantify their predictive skill, the three index series were transformed to instrumental units by linear regression with the instrumental data. The skill measures were quantified based on two calibration/verification intervals using the first and second half of the overlap periods as calibration and verification period, respectively and vice versa. The regression and verification skills of the documentary series are shown in the left columns of Table 2. The snow depth series has the highest r^2 and the smallest loss in variability, whereas the precipitation series has the highest Reduction of Error (RE) [*Cook et al.*, 1994] value as compared to the other series. The standard errors (SE) of estimate, which quantify the uncertainties of the regressions, range between 84% (precipitation) and 88% (runoff) of the instrumental standard deviations (Table 2). The fact that these values as well as the correlations with the measurements and the increase in standard deviation between the two periods (Table 1) are similar for the three series suggests that the method of deriving climate indices from newspapers is robust and applicable to different climate parameters.

4. Extending Documentaries by Degrading Instrumental Data

[8] We generated artificial "pseudo documentary" time series covering the period 1901–2006 for the eight remaining documentary precipitation and runoff records (Figure 1). This was achieved by first adding white noise to the

Table 1. Spearman Correlations of the Indices With the Instrumental Data, Inter-series Correlations in the Historical and Modern Periods as Well as Standard Deviations of the Indices in Both Periods[a]

	Correlation With Instrumental Measurements	Correlation With Runoff		Correlation With Snow Depth		Standard Deviation	
		Historical	Modern	Historical	Modern	Historical	Modern
Mendoza precipitation	0.47 (<0.01)	−0.22 (0.02)	−0.22 (0.07)	0.09 (0.55)	0.06 (0.55)	0.72	1.3
Central Andes snow depth	0.55 (<0.01)	0.32 (<0.01)	0.2 (0.08)			0.97	1.02
Mendoza River runoff	0.43 (0.02)					0.77	0.93

[a]Historical period, pre 1885; modern period, from 1885. The p-values of the correlations are indicated in parentheses.

Table 2. Regression Skill of the Documentaries With Instrumental Overlap Using the Original Indices and the "Pseudo Documentaries"[a]

	Mendoza Precipitation		Central Andes Snow Depth		Mendoza River Runoff	
	Original	"Pseudo"	Original	"Pseudo"	Original	"Pseudo"
r^2	0.18	0.22	0.33	0.30	0.15	0.18
RE	0.45	0.22	0.39	0.31	0.29	0.21
SE [% of instr. std. dev.]	0.84	0.85	0.85	0.79	0.88	0.86
Change in std.dev. [%]	−54	−55	−41	−43	−56	−58
Residual autocorrelation	0.21	0.11	−0.28	−0.17	−0.07	0.00

[a]The r^2, RE, SE values as well as the difference in standard deviation between the measured and reconstructed series and the lag-1 autocorrelations of the regression residuals are listed. All numbers are mean values of two different calibration/verification intervals (1892–1938/1939–1985 for precipitation, 1951–1973/1974–1996 for snow depth and 1909–1934/1935–1960 for runoff).

instrumental data and then allocating them to the index categories of the corresponding documentaries. For all series, we used a target correlation between the degraded and the original instrumental series of 0.45 based on the derived average correlations of the extended precipitation and runoff series (Table 1). We argue that this is adequate, because all documentary series used in this study have been produced with very similar methods, are based on well comparable sources [*Prieto and García-Herrera*, 2009] and have the same index categories (with one exception). For a detailed description of the methodology, we refer to the auxiliary material.

[9] The results were verified by applying the same steps to the three series with instrumental overlap and comparing the results with the original indices (here we used the overlap period correlations from Table 1 as target). The skill measures of the derived "pseudo documentary" series after linear regression are shown in Table 2. The r^2 and SE values as well as the loss of variance compared to the instrumental data are very similar for the original and "pseudo documentary" data. This indicates that the "pseudo documentaries" simulate the regression performance of real documentaries reasonably well, although the RE values are somewhat lower. The lag-1 autocorrelations of the regression residuals of the original and "pseudo documentaries" (Table 2) are all not significant at the 5% level according to the Durbin-Watson statistic. This finding, together with the fact that the distributions of the residuals are very similar in the original and "pseudo documentary" series (not shown), indicates that adding normally distributed white noise is adequate for a realistic degradation of the instrumental data. In order to quantify the potential of the set of extended records, we calculated the fraction of annual precipitation variability of the period 1901–2006 that can be accounted by all the eleven series using multiple linear regressions for each grid cell of the CRU TS3 precipitation grid in SA (Figure 1). Significant portions of variance can be explained in wide regions between 20°S and 40°S, where very few other annually resolved precipitation sensitive proxies exist. Thus, the existing network of documentaries has large potential to complement other annually resolved proxies in a multiproxy predictor network.

5. Conclusions

[10] We present two new newspaper based documentary records of precipitation and snow depth indices from the Mendoza region, which extend the existing historical data to the 20th century. The modern documentaries reflect the fluctuations of the corresponding instrumental data reasonably well at both interannual and decadal timescales and are well comparable to their historical counterparts. We conclude that newspapers are suitable to extend documentary climate records to the 20th century. The Mendoza precipitation series is characterized by a prevailing dry (wet) period in the first (second) half of the 20th century, both being extraordinary in the context of the last 400 years. The number of years with low snow depth has considerably increased in the 20th century as compared to the period 1760–1900. However, the most recent part of the snow depth series, starting in the early 1970s, shows a distinct clustering of years with large snow depth. Our results also suggest that the variability of the hydrological cycle in the Central Andes region was larger in the 20th century, as compared to the previous three centuries. Furthermore, we find that the method of deriving "pseudo documentary" data, which we used to extend eight other historical series to 2006, yields similar, albeit slightly lower regression skill. Finally, we show that the indices explain significant parts of 20th century annual precipitation variance in southern SA, especially in the eastern lowlands between 20°S and 40°S, an area which is very sparsely covered by proxy records from other archives. Hence, this new set of prolonged documentaries allows new insights to be gained about SA precipitation history on local to continental scale and can significantly improve the skill of future multiproxy reconstructions [e.g., *Grosjean and Villalba*, 2005]. Furthermore, the results can serve as a basis for impact studies regarding the long term fluctuations of water availability and associated vulnerability of past and present societies in SA.

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