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Trends and jumps in the annual precipitation in South America, south of the 15°S

JUAN L. MINETTI

CONICET - Departamento de Geografía, Universidad Nacional de Tucumán
Fundación Carl C:Zon Caldenius (NOAA), Argentina

WALTER M. VARGAS

CONICET - Departamento de Ciencias de la Atmósfera, Universidad de Buenos Aires, Argentina

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RESUMEN

Se analizaron los comportamientos temporales de series de precipitación anual de largo período en Sudamérica al sur del paralelo 15°S. Se analizaron cambios en la precipitación promedio de períodos de 30 años encontrándose dos patrones de cambios típicos. El primero en forma de salto o discontinuidad positiva o creciente es dominante al este de la Cordillera; en cambio al oeste de la misma dominan las tendencias negativas. En el primer caso los saltos están presentes durante las décadas de 1950 y 1960. Se analizan las evidencias de ambos tipos de cambios tanto en actividades humanas como en el ecosistema, y se infieren las posibles causas de los mismos.

ABSTRACT

Different types of South American annual precipitation series are analyzed for stations located south of the parallel 15°S. It has been found that the most typical pattern of change in the long-term averages for 30-years consecutive series, corresponding to meteorological stations eastward of the Andes Cordillera, is represented by a "jump" or discontinuity which, for these stations, is always positive. The maximum signal is spotted between the 1950's and the 1960's, showing the largest values on the continental zone of Argentina's territory. On the other hand, for stations on the windward side of the Andes, in Chile, the change is characterized by a decreasing tendency during the years, being steeper over the Northern dessert. Evidences of impacts produced by these changes are shown and possible physical causes of these long-term changes are inferred.

1. Introduction

Changes in long-term annual precipitation means from South American meteorological stations were studied separately for different regions. At the end of a long period of low precipitation in the continental region of Argentina, Weber (1968) analyzed changes in the mean due to trends. Schwerdtfeger and Vasino (1954), by means of a trend analysis showed a differential behavior in the same region since beginning of the century, with a decreasing annual precipitation mean in the continental region and an enhanced mean over the eastern region of Argentina, called Mesopotamia.

After an important drought on western Argentina, at the end of the 1970's, downward trends of precipitation and surface river drainage of the Andean region and Central Chile were analyzed (Frick, 1977; Agua y Energía Electrica, 1981; Minetti, 1985; Minetti and Carletto, 1990). Barros and Mattio (1978), and Barrros and Rodriguez Seró (1979) analyzed important long-term changes in the precipitation over the northern plateau of the Patagonia -southern region of Argentina-, especially during the rainy period that occurred in the 1940's. These changes are also shown by Minetti (1985) through analysis of the regional precipitation in Chile between 35°and 42°S. In the Northwest of Argentina and Cuyo, both continental regions of Argentina, the annual precipitation mean had a sudden increase in the 1950's. This could be a byproduct of an important cooling in the mean and mean maximum temperature, together with cloudiness increase (Minetti and Vargas, 1983a; Minetti and Vargas, 1983b; Minetti and Poblete, 1989; Minetti, 1991; Minetti and Vargas, 1996; Compagnucci *et al.*, 1982). On the other hand, the temperature and cloudiness could be byproducts of the precipitation, or all three could be byproducts of the general circulation.

Long-term changes in the annual precipitation of the Argentina's Mesopotamia, its dry Pampa, and the provinces on the western portion of the country, are shown in recent papers by Minetti and Vargas (1996) and Castañeda and Barros (1994).

Flohn (1968), for the Northeast of Brazil, and more recently Kousky and Shin Chu (1978), worked on long-term trend and changes in precipitation over the northern portion of the South American region below 15°S.

The description of these phenomena related to large scale changes in the regional circulation was undertaken by Schwerdtfeger and Vasino (1954), Diaz (1959), Pittock (1980), Minetti *et al.* (1982b), Minetti *et al.* (1987), Vargas *et al.* (1995), Castañeda and Barros (1994), Barros *et al.* (1996), and Barros and Moyra (1996). Some of these studies have also considered effects brought up by changes in atmospheric CO2 on hemispheric circulation patterns and consequently precipitation distribution (Minetti *et al.*, 1982a; Kugler, 1983; Minetti and Sierra, 1984; Vargas, 1987; Ivanissevich, 1989; Sierra *et al.*, 1994). Comprehensive synthesis for larger scales was presented by Barnett (1985), Ellsaesser *et al.* (1986) and Diaz *et al.* (1989).

Recent investigations indicate that changes in annual precipitation mean and other variables in Argentina showed up as a jump and not as a trend (Minetti and Poblete, 1989; Minetti and Vargas, 1996), possibly originated by a discontinuity in wet advection intensity from the Northeast (Vargas *et al.*, 1995). Instead, precipitation trends in Chile would show a different source for the observed long-term changes.

The present work aims to integrate the regional knowledge based on the sparse information available, to determine the statistical nature of nonhomogeneities, and to infer some of the causes which might explain the observed changes.

2. Data and Methods

The basic data have been provided by national meteorological services of Argentina, Bolivia, Brazil, Chile, Paraguay (edited by the World Weather Records, Smithsonian Institution 1929, 1934, 1947, and U.S. Department of Commerce NOAA 1959, 1966, 1982, 1991), and Chile (CORFOP, 1969, appropriately up-dated).

The information available in its large majority includes data from the end of the last century until the 1980's and beginning of the 1990's. Locations with series of at least 60 years long and showing no important gaps in their records were selected. Isolated missing data were completed by means of multiple interpolation with weighted polynomial method (Quintela, 1982).

Sixty year series are needed in order to compare at least two average values coming from consecutive subseries 30 years each. Thirty years of data are needed to obtain stable means with an error less than 5% in semiarid regions; shorter records may satisfy the need in wet regions. However, in the case of desert areas more than 50 years of data are required (Minetti *et al.*, 1986).

Relative and absolute homogeneity tests (WMO, 1966) through trend and jump analysis were applied to the real data or to its differences with nearby locality data series. The analysis of trends and jumps was subjected to Student's t-test (Chatfield, 1980; Spiegel, 1969) to define the slope coefficient "b". The "Y" of Yamamoto *et al.* (1985) and "L" of Leith (1978) tests were applied to the mean discontinuities (jumps), as already used by Vargas *et al.* (1995).

Trends were estimated with least squares according to (1). The slope coefficient, "b", is tested with the t-statistic given by equation (2) (Miller and Freund, 1973).

$$b = \frac{\hat{S}_{xy}}{\hat{S}_{xx}} \tag{1}$$

$$''t'' = \frac{b-\beta}{\hat{S}_e}\sqrt{\frac{\hat{S}_{xx}}{N}} \sim t_{(N-2)} \tag{2}$$

with: $H_o \; : \; \beta = 0$ and $H_j \; : \; \beta \neq 0$.

b is the slope of the regression obtained by least squares, β is the hypothesis slope, N is the number of data, H_o is the null hypothesis and H_j, the alternative hypothesis, and

$$\hat{S}_{xy} = N\sum_{i=1}^{N} x_i y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i$$

$$\hat{S}_{xx} = N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2$$

$$\hat{S}_e = \sqrt{\frac{\hat{S}_{xx}\hat{S}_{yy} - \hat{S}_{xy}^2}{N(N-2)\hat{S}_{xx}}}$$

The description of the tests used to detect the years of occurrence of climatic jumps are the following:

a) 'L'

$$L = \frac{\Delta\mu}{s} \tag{3}$$

where $\Delta\mu$ = variation of averages ($\Delta\mu = Mb - Ma$). Mb and Ma are averages before and after the reference year. S = Standard deviation of averages with:

$$S = \frac{Sm}{\sqrt{N}}$$

S is used when there is no dependence between the dates, and two normal universes with the same variance occur. Sm = standard deviation of the sample with:

$$Sm = \sqrt{\frac{(Nb-1)Sb^2 + (Na-1)Sa^2}{Nb + Na - 2}}$$

Sb and Sa are the standard deviations before and after the reference year. Na and Nb are periods before and after the reference year, respectively.

Detection of jumps is presumed for a S/N ratio greater than or equal to 1.0. It is understood that no jumps are detected when S/N ratios are less than 1.0.

b) 'Y' Signal/Noise ratio used by Yamamoto *et al.* (1985) for the reference year.

$$Y = \frac{Ma - Mb}{Ca - Cb}$$

where

$$C = \frac{Sxtq}{\sqrt{n-1}}$$

and Ca and Cb are the confidence limits of probability (P%) before and after the occurrence of climatic jumps. Sx represent a variable whose values may be represented by Sb and Sa to define the respective confidence limits. Sb and Sa are computed for examples of size N before and after a specified year which is shifted in turn; tq is the value in the Student distribution with probability $q\%$ $(= 100 - p)$.

It is reasonable to conclude that a discontinuity of the time means could be detected with $p\%$ confidence of the reference year, when S/N value might be greater than unity.

c) 't' Student for the difference between two consecutive means.

$$tc = \frac{(Mb - Ma) - (\mu_b - \mu_a)}{Sm\left(\frac{1}{Nb} + \frac{1}{Na}\right)} \tag{4}$$

where: $\mu_b - \mu_a$ is the expected difference between Ma and Mb according to the "null" hypothesis, which for this case of randomness, is appropriately set as equal to zero. For the "null" hypothesis of randomness, the distribution 't' given by (4) follows the Student t- distribution for $(Na + Nb - 2)$ degrees of freedom. The tests should ordinarily be based on a comparison of magnitude 'tc' with the 95% probability points of 't' distribution appropriate to a two-tailed form of test. If an only 'tc' lies beyond this 't' we should accept the difference between two non-overlapping sample means as evidence of inconstancy or climatic jump.

In the context of this paper it is understood that a "jump" is detected when the 'L', 'Y' and 't' tests are simultaneously significant.

To ensure the required average's stability, the analysis undertaken was based on the experienced gathered in frequent regional data processing activities. Specific considerations were developed in previous research activities on the critical lengths of the series needed to justify averages, with errors equal or less than 5%, in cases where the series degree of variability and asymmetries play an important role (Menegazzo *et al.*, 1985; Minetti *et al.*, 1986; Poblete *et al.*, 1989). In this regard the arid regions within the study area did not fully satisfy these considerations; therefore the comparison amongst the 30-year long subseries was very thoroughly and carefully undertaken. Furthermore, the quality of the precipitation data was screened on the basis of the information and analysis methods developed by Hoffmann (1970). These also involve the effect of changes in human activities and the impacts of environmental changes in the proximity of the meteorological stations.

3. Results and discussion

Figure 1 shows the region under study and the location of the stations analyzed. Table 1 provides information on their geographic location and the data periods. From the spatial analysis of absolute nonhomogeneities, an abrupt jump in the mean appears in almost all the stations eastward from the Andes Cordillera. The "t", "Y" or "L" tests point out significant differences in the subseries mean, before and after the maximum signal date, when this kind of change occurs.

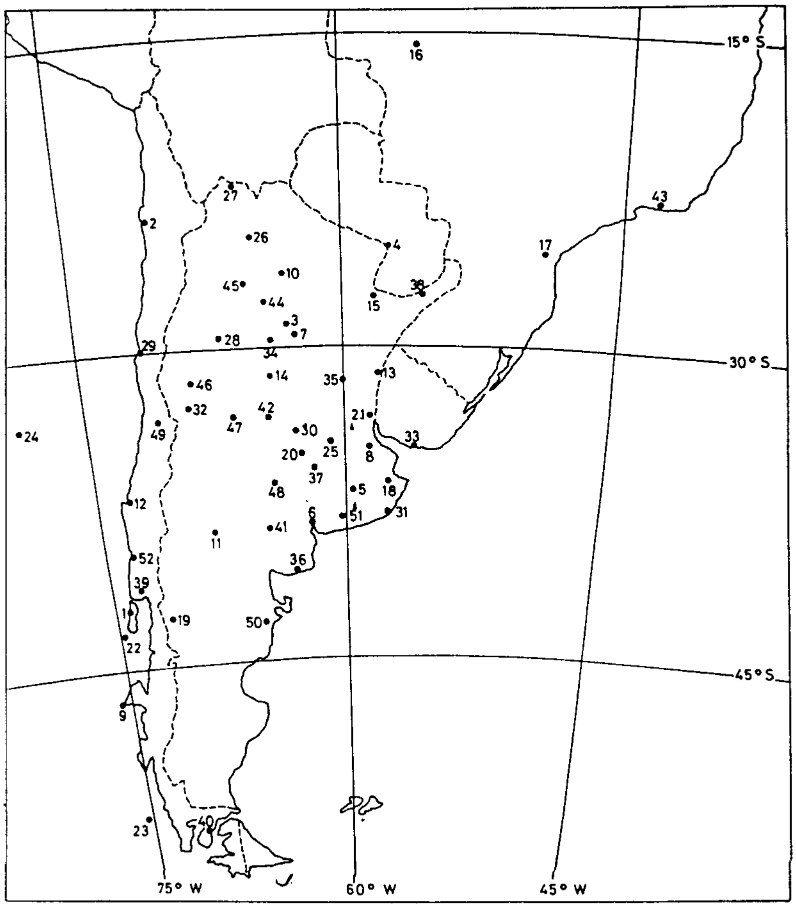

Fig. 1 Study region and pluviometric network used. The name of each numbered location is given in Table 1.

Table 1. Meteorological stations and precipitation measurements used in this study.

N°	Station	Latitude S	Longitude W	Height (m)	Period
1	Ancud (Chile)	41° 52'	73° 49'	30	1888-1987
2	Antofagasta (Chile)	23° 26'	70° 28'	119	1904-1980
3	Añatuya (A-Buenos Aires)	28° 28'	62° 50'	108	1912-1993
4	Asunción (Paraguay)	25° 16'	57° 38'	64	1881-1980
5	Azul (A-Buenos Aires)	36° 45'	59° 50'	132	1888-1990
6	Bahia Blanca (A-Buenos Aires)	38° 44'	62° 11'	70	1860-1993
7	Bandera (A-Santiago)	28° 54'	62° 16'	90	1911-1993
8	Buenos Aires (A-Cap. Federal)	34° 35'	58° 29'	25	1861-1990
9	Cabo Raper (Chile)	46° 50'	73° 35'	40	1914-1980
10	Campo Gallo (A-Santiago)	26° 35'	62° 51'	190	1924-1993
11	Cipolletti (A-Rio Negro)	38° 57'	67° 59'	265	1900-1993
12	Concepción (Chile)	36° 50'	73° 03'	10	1866-1981
13	Concordia (A-Entre Rios)	31° 23'	58° 02'	38	1903-1993
14	Córdoba (A-Cordoba)	31° 24'	64° 11'	425	1873-1993
15	Corrientes (A-Corrientes)	27° 28'	58° 49'	60	1873-1993
16	Cuiaba (Brazil)	15° 35'	56° 06'	165	1901-1980
17	Curitiba (Brazil)	25° 26'	49° 16'	949	1885-1980
18	Dolores (A-Buenos Aires)	36° 21'	57° 44'	9	1901-1990
19	Esquel (A-Chubut)	42° 52'	71° 09'	705	1896-1993
20	Gral. Villegas (A-Buenos Aires)	35° 02'	63° 01'	115	1898-1990
21	Gualegauychú (A-Entre Rios)	33° 00'	58° 37'	24	1901-1993
22	IS.Evamgelista (Chile)	52° 24'	75° 06'	55	1899-1980
23	Isla Guafo (Chile)	43° 34'	74° 45'	140	1908-1980
24	Juan Fernandez (Chile)	33° 37'	78° 52'	6	1901-1980
25	Junin (A-Buenos Aires)	34° 35'	60° 56'	81	1901-1993
26	La Esperanza (A-Jujuy)	24° 13'	64° 53'	550	1900-1994
27	La Quiaca (A-Jujuy)	22° 06'	65° 36'	3454	1908-1980
28	La Rioja (A-La Rioja)	29° 23'	66° 49'	430	1904-1993
29	La Serena (Chile)	29° 54'	71° 15'	132	1869-1980
30	Laboulaye (A-Cordoba)	34° 08'	63° 24'	138	1903-1993
31	Mar del Plata(A-Buenos Aires)	38° 08'	57° 33'	24	1888-1993
32	Mendoza (A-Mendoza)	32° 53'	68° 51'	827	1982-1993
33	Montevideo (Uruguay)	34° 58'	56° 12'	22	1881-1980
34	Ojo de Agua (A-Santiago)	29° 30'	63° 20'	550	1911-1993
35	Paraná (A-Entre Rios)	31° 47'	60° 29'	62	1901-1993
36	Patagones (A-Buenos Aires)	40° 47'	62° 59'	40	1898-1993
37	Pehuajo (A-Buenos Aires)	35° 52'	61° 54'	87	1897-1993
38	Posadas (A-Misiones)	27° 22'	55° 58'	133	1903-1993
39	Puerto Montt (Chile)	41° 25'	73° 05'	85	1888-1987
40	Punta Arenas (Chile)	53° 10'	70° 54'	20	1888-1980
41	Río Colorado (A-Rio Negro)	39° 01'	64° 05'	79	1900-1991
42	Rio Cuarto (A-Cordoba)	33° 05'	64° 16'	421	1900-1993
43	Rio de Janeiro (Brazil)	22° 54'	45° 10'	27	1851-1980
44	S.del Estero (A-Santiago)	27° 46'	64° 18'	199	1903-1993
45	S.M.de Tucumán(A-Tucuman)	26° 48'	65° 12'	481	1884-1994
46	**San Juan (A-San Juan)**	**31° 36'**	**68° 33'**	**630**	**1875-1993**
47	**San Luis (A-San Luis)**	**33° 16'**	**66° 21'**	**716**	**1903-1993**
48	**Santa Rosa (A-La Pampa)**	**36° 35'**	**64° 16'**	**189**	**1902-1990**
49	**Santiago (Chile)**	**33° 27'**	**70° 42'**	**520**	**1869-1980**
50	**Trelew (A-Chubut)**	**43° 14'**	**65° 18'**	**39**	**1902-1983**
51	**Tres Arroyos (A-Buenos Aires)**	**38° 23'**	**60° 16'**	**109**	**1888-1993**
52	**Valdivia (Chile)**	**39° 48'**	**73° 14'**	**5**	**1876-1980**

Note: The letter A indicates that the location belongs to Argentina, and the name following this letter indicates the province of this country.

The few stations which do not show any change of this kind are: San Juan, Tres Arroyos, Paraná, and Pampa de los Guanacos, in Argentina, and Cuiaba in Brazil.

Nevertheless, from a mere statistical point of view, these locations would have relative non-homogeneities with respect to other close stations. Since discontinuities could be masked by smooth precipitation trends along the years; this would be a reason for the absence of a jump in the averages of some of these stations.

These "jumps" in the precipitation have brought sudden changes on the natural and managed ecosystems. This would explain the agricultural expansion registered in eastern semiarid borders of the agricultural oasis of the Argentina's northwestern and northeastern portions and on the western sectors of the Bonaerensis Pampa. This expanded the so called humid pampa towards the province of La Pampa, upgrading the dry-semiarid areas to the sub-humid level (see regions A, B and C in Fig. 2).

Fig. 2. Some regions affected by the precipitation long term changes: important agricultural expansions in semiarid regions (A, B and C); frequent floods (D); inland lakes of flooded areas: Mar Chiquita, Encadenados and Chascocmús (E1, E2, and E3 respectively). Argentina provinces numbered in the map: 1-Jujuy, 2-Salta, 3-Formosa, 4-EL Chaco, 5-Santiago, 6- Tucumán, 7-Misiones, 8-Corrientes, 9-Catamarca, 10-La Rioja, 11-San Juan, 12-Córdoba, 13- Santa Fe, 14-Entre Rios, 15-Mendoza, 16- San Luis, 17-Buenos Aires, 18-La Pampa, 19-Neuquen, 20-Rio Negro, 21-Chubut, 22-Santa Cruz, 23-Tierra del Fuego, 24-Capital Federal.

This effect is also noticed southward of San Luis and Cordoba provinces. Surface enlargement of inland lakes, such as Mar Chiquita, Las Encadenadas and Chascomús, among others, (De Petre and Espino, 1983; Boragni, 1992; Fuentes, 1983; Villalonga, 1993) also has to do with this agricultural expansion, as well as with the floods caused by increased flow in some inland basins, such as the Río V basin (La Nacion, 1987; Ivanissevich, 1989) (see regions D, E1, E2, and E3 in Fig. 2). Some of these series, with their long-term changes in the mean, can be seen in Figure 3.

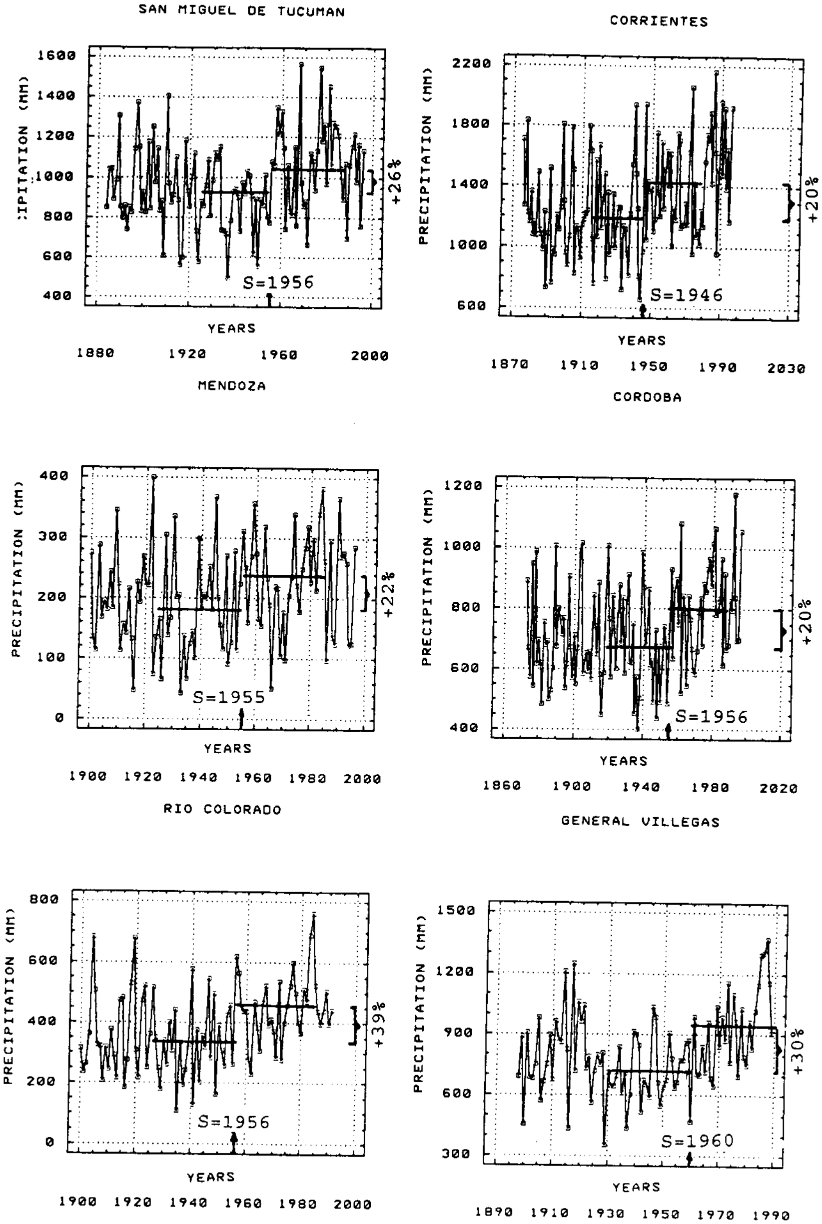

Fig. 3. Positive jump examples in annual precipitation eastward of the Cordillera de los Andes. Arrows indicate the jump's date. The number on the right of the figure indicates the maximum average change between consecutive 30 year series. The letter S indicates the date of maximum signal to noise ratio. 30 year averages before and after the jump are plotted.

Westward of the Andes Cordillera, in Chile, almost all long-term changes are negative trends showing some small jumps in several phases (Frick, 1977). This behavior, added to the undue anthropic pressure, has generated a dessertification process showed by Gasto and Contreras (1979) and Etienne *et al.* (1983) (see region F in Fig. 2). An exception to this pattern is the region between 35 S and 42 S, more noticeable in the surroundings of Chiloe and Guafo islands, where an increase in precipitation of the jump kind can be found. This negative trend can be noted also in the rivers of Cuyo region following a North-South transect (Agua y Energía Electrica, 1981). Decreasing trends in precipitation appear again towards the South of Chile. The slope of the decreasing trends are steeper over the continent in Chile than over the oceanic region. In fact, the meteorological station in Juan Fernandez Island presents a small decreasing trend. Some characteristics identifying these absolute nonhomogeneities are presented in Figure 4.

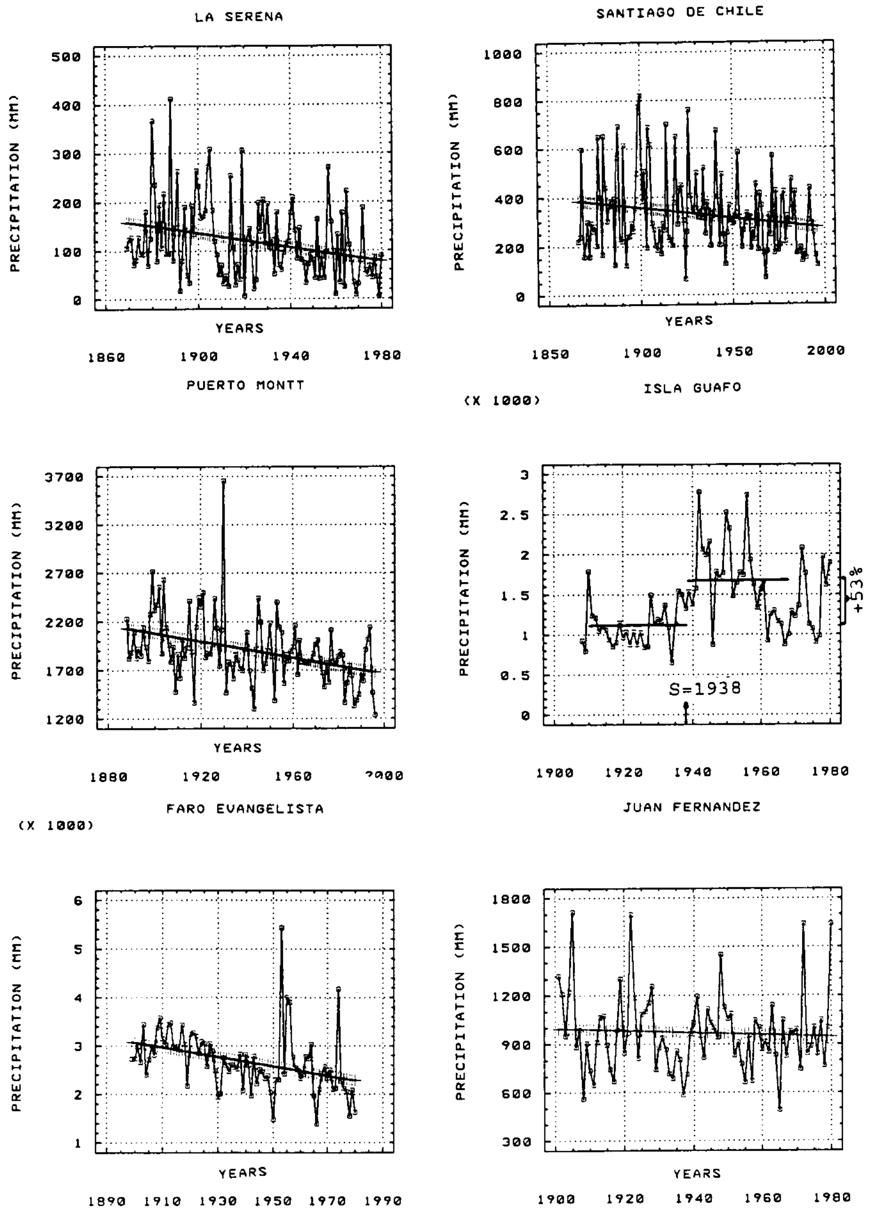

Fig. 4. Examples of negative trends and positive jumps in annual precipitation westward the Cordillera de los Andes. One station present a positive jump during the year 1938 inidcated with an S. 30 year averages before and after the jump are plotted (Guafo island).

Figure 5 shows the isochronal field corresponding to years of larger change in the annual precipitation mean between consecutive 30 years long subseries. These years are detected by means of methods for climatic jump location for the maximum relation signal/noise. Toward the east of the Cordillera, drawing of the map was rather simple because only one date was detected around which a jump took place. In more continental regions, this field shows up at the beginning of the 1960's, and the length of the consecutive subseries (30 years) does not define jumps farther than 1964. In the case of the region located west of the Cordillera, on Chilean territory, multiple jumps and negative tendencies prevent drawing of the jump isochrons.

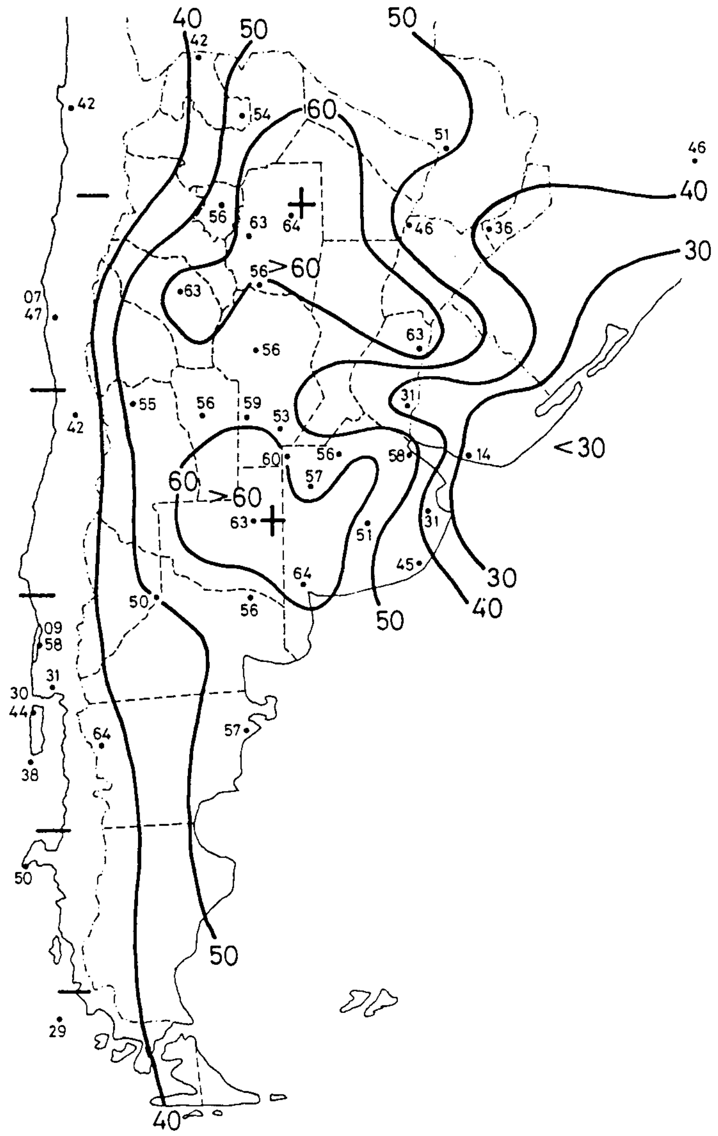

Fig. 5. Isochrons of years registering the main change in the mean of annual precipitation. Each number must be read plus 1900; i.e. 40 means 1940.

Figure 6 shows the percentage difference of the precipitation between two consecutive 30 year subseries obtained with equation (5).

$$Dif(\%) = [(\overline{Ra} - \overline{Rb})/\overline{Rb}]100 \tag{5}$$

where:

$\overline{Ra}$ = precipitation mean of 30 years after the jump

$\overline{Rb}$ = precipitation mean before the jump.

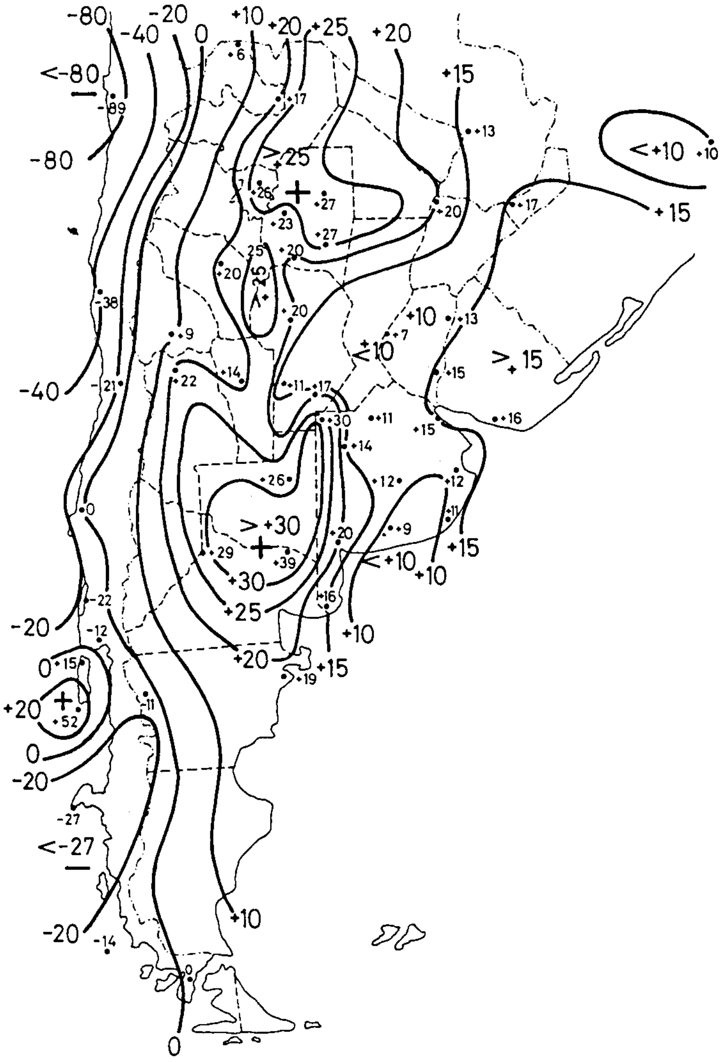

Fig. 6. Percentage change in the mean of long-term precipitation during the years indicated in Figure 5.

From figures 5 and 6 it can be seen that the greatest percentage difference in annual mean precipitation occurred at the beginning of the 1960's in the continental zone of Argentina, Paraguay and Bolivia. These are definitive changes, not errors in measurement, which were clearly verified through their environmental impacts. They exceed the 25% registered in regions of semiarid climate. Since an error in the subseries average counts for less than 5%, these changes turned into significant and important impacts, particularly on the West of Buenos Aires and East of La Pampa, in Argentina.

Both of these regions passed from a very dry period with active soil degradation by wind erosion analyzed by Kugler (1983), to a period of hydrological excess with floods, as described by Fuentes (1983), Vargas (1987), Ivanissevich (1989), and Boragni (1992) among others.

Another proof of this change is the explosive agricultural expansion registered in the last 30 years in the semiarid margins of the Northwestern and Northeastern regions of Argentina (see Fig. 2, regions: A and B) west of Buenos Aires, and east of La Pampa provinces, where today wider agricultural prairies can be found (Minetti and Sierra, 1984; Sierra *et al.*, 1994). It should be remarked that although other factors contributed also to the agricultural expansion along the Pampa's semiarid margins, such a development would not have been possible without this natural resource advantage.

Within the zone where the largest changes are observed, two important nuclei or centers of a considerable extension can be identified: one located east of the Bolivian-Argentine forest, west of Paraguay, Santiago del Estero province, east of La Rioja and northwest of Cordoba (Minetti and Poblete, 1989; Minetti, 1991), and the other located west of Buenos Aires, La Pampa province, east of Cuyo and north of Patagonia (Compagnucci *et al.*, 1982; Hoffmann, 1988, Minetti and Vargas, 1996).

Over the arid zone of the east of Mendoza and north of Patagonia, results are less defined. This is probably due to the effect of series length which, being of less than 30 years, makes it difficult to obtain a mean with a 5% error or less.

The greatest jump in annual precipitation begin to smooth towards the east, until it turns into an increasing trend; however, there are jump signals in the statistical analysis. In the case of Chile, Table 2 shows that the greatest absolute nonhomogeneities are given over the northern desert and the transition semiarid region at the center of the country. This fact is not surprising since "the dessert margins have fluctuated during the last ten thousand years" according to Hare (1977).

Table 2: Percentage changes due to trend effects in 100 years with respect to the mean in locations of the north and south of Chile, except Chiloe Island and its surroundings which have a different pattern of long-term change in the mean.

Location	Change = Dif. × 100 years trend / average
Antofagasta	1.70
La Serena	0.62
Santiago de Chile	0.17
Valdivia	0.19
Puerto Mont	0.21
Cabo Raper	0.52
Islote Evangelista	0.37

Note: Dif = trend value at the end of the series - trend value at the beginning of the series

$$\text{average} = \left(\frac{1}{N}\sum_{i=1}^{N} x_i\right)$$

Over the northern limit of the studied region, the data sparsity does not permit any important long-term changes in the mean.

From the information presented here and knowledge on the regional circulation variability, it can be inferred that further east of the Andes Cordillera the early increase in precipitation in the maritime littoral could be linked to an increase in sea temperature over the 1930's and 1940's (Barnett, 1983) and the related increase in water vapor availability for enhancing the precipitation processes. On the west of Argentina, where the maritime tropical air converges, the observed precipitation jump coincides with that of the vapor advection intensity, as shown by Vargas *et al.* (1995).

The jump delay over the arid-semiarid more continental zone of Argentina in the early 1960's could be due to a more complex mechanism in the climatic system. In the 1950's gradual soil moistening of the western region and increased water vapor convergence with associated cloudiness and precipitation, caused a greater though delayed drainage of surface and underground water towards the eastern semiarid region. This process would be set up by a more humid convection in that region with an increase in the total precipitation. Other authors (Weijer and Vellinga, 1995) in the large global scale, increase in mean surface temperature (perhaps due to the greenhouse increment) meant more global evaporation and hence larger quantities of precipitable water.

From the previous standpoint this inertial system, generated by the internal hydrological cycle, would damp the droughts produced by high frequency variability of the system. Downward trends in Chilean precipitation might be explained by the global heating of the Earth due to increasing CO_2 content. As a result, a decrease of the latitudinal thermal gradient would affect directly the latitudinal position of the subtropical jet current and the subtropical anticyclonic axis as, stated by Smagorinsky (1963) in equation (6).

$$tg\phi = (H\Delta T/\Delta Z)/(R\Delta T/\Delta\phi) \tag{6}$$

where:

ϕ: latitude of the subtropical jet current, approximately above the surface position of the subtropical anticyclone axis

$\Delta T/\Delta Z$: vertical thermal gradient

$\Delta T/\Delta\phi$: latitudinal thermal gradient.

R: radio of the Earth

H: mean level of 500 hPa

The gradual southern motion of the Pacific anticyclone from its normal position has a negative and significant correlation with the amount of precipitation over the central Chilean zone according to Minetti *et al.* (1982b). This phenomena, also observed on the Atlantic Ocean, would not explain the occurrence of jumps instead of trends. The long-term increase of precipitation registered near Chiloe Island could be related to inversions in the wet advection intensity of the Pacific (western) at the same latitude, due to the inverse relation between central and southern pressure gradients affecting this country (Minetti *et al.*, 1982b). In this case movement to the south by the Pacific anticyclone produces a decrement in the west advective component over the central zone in Chile and an increment further south. This fact would lead to an increase in regional precipitation, limited by an enhanced subsidence with the southward displacement of the anticyclone.

The small trend in precipitation in Juan Fernandez island, compared to trends observed in the Chilean continental zone, might indicate that an increase in anticylogenesis over the coast would be responsible for a downward trend in Chilean precipitation. Sign changes in precipitation long-term variations in both sides of the Cordillera's southernmost part would explain the absence of significant trends according to results of Hoffmann (1988) and Barnett (1985).

In the particular case of Chile, Figure 6 shows the percentage variation of the main jump.

4. Conclusions

Two kinds of absolute nonhomogeneities were found in precipitation series south of the latitude 15°S in South America. A jump is noteworthy east of the Cordillera, while westward changes appear as downward trends.

The greatest variations in the mean, from the end of the past century until the present, have occurred in the north-central region of Chile and over the Argentine continental zone (east of the Bolivian-Argentine forest, and Argentine provinces of Santiago del Estero, La Rioja, Cordoba, La Pampa and west of Buenos Aires).

Both kind of changes have brought about important effects on human activity. Therefore, although the data present some quality problems affecting, to some extent, the time climatic series, the hypothesis that the "jumps" observed may be the result of measurement errors is a wrong judgment.

Isochrons of positive jump dates in the mean east of the Cordillera show variations in the change date. Some occurred in the 1930's or earlier over the maritime littoral, up to the 1950's and 1960's in the most continental Argentine zone. In Chile, absolute nonhomogeneities appear as downward trends with a different model at Chiloe island.

All the changes shown east of the Andes Cordillera might be caused by an increase in sea temperature and a jump in northeast wet advection intensity. The source of the regional circulation jump is unknown.

West of the Cordillera, the downward trend in precipitation might be due to an increase in anticyclogenesis over the eastern border of the subtropical anticyclone in the South Pacific ocean rather than to a latitudinal position shift.

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