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THE 2000-2002 FLOOD EVENTS IN BUENOS AIRES PROVINCE, ARGENTINA

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ABSTRACT: This study assesses the evolution caused by an important flood during 2000–2002, in Buenos Aires province. It is located in the main rain-fed region of Argentina and presents a lot of cities of different importance and population. The mean soil uses are crops (maize, wheat and soybean) and livestock for meat or milk production. The hazard began in October 2000, and for this, soils were with soil water surplus. This means that its absorption capacity and storage were at its limit and the water table's height at very little depth. In 2001, there were two flood cycles, one earlier this year and another at the end of it. During 2002, the surpluses were higher than 300 mm reaching values of 500 mm. Although it has been shown that such events are more frequent in the warm phase of ENSO or El Niño, this was not a case of "El Niño" which recently appeared at the end of the event when its worst consequences had already passed. Statistical analysis of rainfall and soil water surplus shows that this was an event of very low probability of occurrence, in most of the provincial surface.

Keywords: Flood Event, ENSO, El Niño, Flood Management, Southern Oscillation Index.

1. INTRODUCTION

Flood management is a broad concept that uses a combination of policy, regulatory, financial and physical measures which focus on coping with the hazard posed by floods, while recognizing that they can never be fully controlled.

The activities of humans depend, among other factors, the environment that surrounds them. Their variability and climate change depend mainly on the change in the frequency of occurrence and intensity of extreme events. In mid-latitudes, high and low temperatures and precipitation deficits or excesses are the more extreme events that affect the population.

The north eastern region of Buenos Aires province is part of the Del Plata basin, fifth basin in the world by its magnitude, generating about 70% of Gross Net Proceeds of the five member countries,–Argentina, Uruguay, Paraguay, Brasil and Bolivia-with a population over 100 million inhabitants. In particular, in our region are often extreme and persistent water problems (excesses or deficits), which have a significant socio-economic impact. Their study in terms of climate, and analysis of the agrohydrologic conditions associated help to understand by providing tools for management and forecasting.

Regarding rainfall in Argentina has presented a steady increase of total precipitation over time in different time scales (annual, seasonal, etc.). This increase shifted westward the agricultural frontier about 200 km, being thus substantially favoured farming in certain regions in Argentina, especially semi-arid areas. Some of them are situated in western area of Buenos Aires province, with soils suitable for certain crops.

Since the 70's several scientific studies noted increases in total annual and seasonal precipitation in various regions of Argentina. Barros and Doyle (1996) noted that, in southeastern Brazil and northern Argentina, the positive trends begun in the mid 70's, and in southern Argentina from the 60's.

Among the more recent studies may be cited Barros and Castaneda (2000) who studied trends in seasonal rainfall during the period 1959-1996 at North of 40° S and so did Liebmann *et al.* (2004) in the southern South America for the period 1976-1999. Numerous articles relate to El Niño-Southern Oscillation (ENSO) with the inter-annual variations in precipitation in Argentina, (Pittock, 1980, Aceituno, 1988, Barros *et al.* 1996), found negative correlations between the Southern Oscillation Index (SOI) and rainfall in central and southern Buenos Aires province, particularly during the spring months. Grimm *et al.* (2000) observed that large anomalies in precipitation events during El Niño and La Niña are related to anomalies in atmospheric circulation over South America.

From a climatological point of view, Labraga *et al.* (2002) analyzed the atmospheric circulation associated with the excesses and deficits of rain in the Argentine pampean region. Rainfall and discharge trends were also compared in Karkhe basin, Iran (Eslamian and Khordadi, 2009).

Scarpati *et al.* (2007) found that water surpluses occur in almost all years, but they are particularly marked during the El Niño phase of ENSO, and least during La Niña.

Scarpati *et al.* (2002) concluded that there is a weak but statistically significant relationship between El Niño driven climate variability and positive Salado River discharge anomaly in May, providing 35% of the explanation for the high flows.

The surface of Buenos Aires province is 307,571 km^2 and it is a large plain with elevations below 300 m. The hills of Tandilia and Ventania, located in the south of the province, reach maximum heights of 520 m and 1,240 m respectively. The drainage system consists of meandering rivers that are partially connected to permanent and seasonal lagoons. The low slope regional gradient leads to the detention of rainwater for long periods, in various forms of storage, mainly in the soil, on the floodplain and in shallow lagoons. This favours vertical water fluxes (evaporation and infiltration) rather than lateral runoff. The vertical hydrologic fluxes of rainfall and evapotranspiration are more concerned in regions of limited relief, like the study area, than horizontal surface and subsurface flows. A soil water surplus occurs during periods with precipitation exceeding evapotranspiration. During such periods, once soil storage capacity is achieved, the soil water table is elevated. Eventually, the water surplus is unable to infiltrate because the water table is so close to the surface, a common occurrence in many low-lying areas of the Buenos Aires province. The water table rises to the surface, thereby increasing the flood potential and the area of lakes, ponds and surface impoundments.

When water table is very close to the surface, indicates that surface waters (ponds) and groundwater are strongly related, so they should be treated as part of a single system. The water table fluctuations are important indicators of hydrologic behavior. Forte Lay *et al.* (2007) showed the relation between the soil water balance and variations in the depth of water table for different pampean stations.

The flood began in October 2000, had two peaks in 2001 (one in March and another in October) and finished in March 2002, therefore, this study emphasizes the results found for the months above mentioned.

The height of Salado River was one meter more in March 2002 (2.75 m) than in March 2001 (1.75 m) at General Belgrano hydrometric station according the National Water Institute (2002). The mean height of Salado River is 0.50 m and its mean flow is $80m^3/s$.

The floods had for the agricultural sector losses upper than U$S 700 million and as producers of the affected areas a higher value. In the livestock sector, producers, according to official estimates, have lost U$S 23 million and the damage caused by flood in rural infrastructure was U$S 27 million. The water erosion ruined the 80 per cent of the roads belonging to the secondary provincial network, or, connecting the rural areas to the cities.

The objective of this paper is to analyse the above mentioned severe floods occurred in 2001–2002, when heavy rains caused an unusual soil water surplus.

2. MATERIALAS AND METHODS

Figure 1, shows the hydrographic network in the studied region.

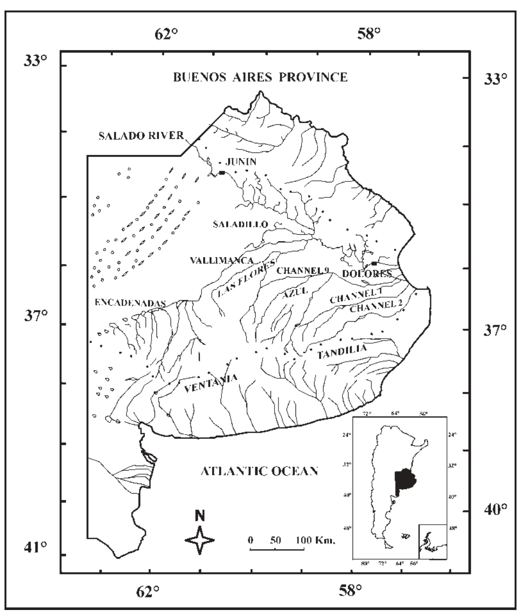

Figure 1: The Hydrographic Network of the of the Buenos Aires Province

Daily precipitation data referring to the last 40 years period 1968-2007, have been provided by the National Meteorological Service (29 stations in the province) and by the National Institute of Agronomic Technology–INTA (5 stations in the province), and 12 stations in the surroundings of Buenos Aires province which help in the construction of the isolines maps. Figure 2, shows the location of meteorological stations used, while, Table 1 reports their names and codes.

Table 1
Denomination and Code of the Meteorological Stations Shown in Figure 1

Number	*Stations*	*Number*	*Station*
1	San Pedro INTA	**18**	Daireaux
2	Pergamino INTA	**19**	Santa Teresita
3	Junín	**20**	Azul
4	San Miguel	**21**	Olavarría
5	Mariano Moreno	**22**	Tandil
6	Aeroparque J. Newbery	**23**	Villa Gesell
7	Buenos Aires	**24**	Coronel Suarez
8	Ezeiza	**25**	Laprida
9	General Villegas	**26**	Pigüé
10	La Plata	**27**	Benito Juárez
11	Nueve de Julio	**28**	Balcarce INTA
12	Punta Indio	**29**	Bordenave INTA
13	Pehuajó	**30**	Coronel Pringles
14	Trenque Lauquen	**31**	Mar del Plata
15	Las Flores	**32**	Tres Arroyos
16	Bolivar	**33**	Bahía Blanca
17	Dolores	**34**	Hilario Ascasubi INTA

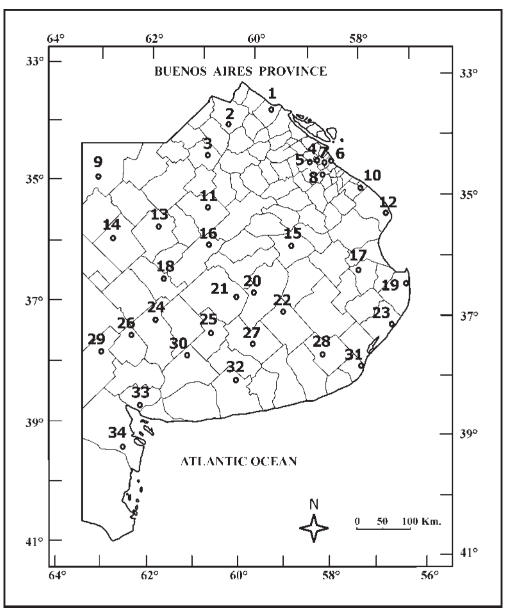

Figure 2: Territorial Distribution of the Meteorological Stations Indicated in Table 1

The spatial and temporal variability of the soil water content have been obtained using the Forte Lay and Aiello (1996) method which allows the estimation of the soil water content and its anomalies. This algorithm is based on daily soil water balance method of Thornthwaite and Mather (1955) and uses the measured precipitation and the daily mean reference evapotranspiration. Normal mean monthly reference evapotranspiration for the period 1961-2004, was calculated by the Penman-Monteith method (Allen *et al.*, 2004).

The soil water balance is:

$$PP + EP + \Delta St + Su = 0$$

where:

PP = precipitation

EP = reference evapotranspiration

ΔSt = soil water content variation

Su = soil water surplus

For the statistical study, the series of water surplus data obtained for the period 1968-2007, have been adjusted following Forte Lay and Troha (1992), by means of the theoretical Normal Cubic-root probability distribution. The obtained annual and monthly precipitation series have been fitted using the same theoretical probability distribution of frequencies (Troha, 1978). This method gives similar results with respect to the Incomplete Gamma and Weibull methods. The normal distribution for short periods (a month or a shorter period) is asymmetric, thus its use is not recommended in these circumstances. The method used in this study has allowed

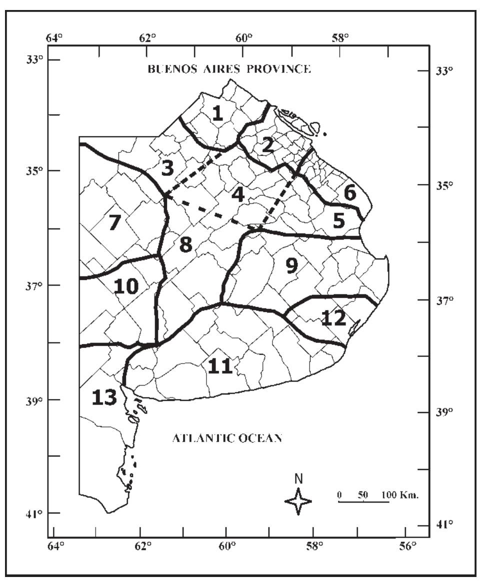

Figure 3: Buenos Aires Province Repartition in Hydrologic Sectors According with the National Water Resources (2002). The Dashed Lines Show the Three Areas of Salado River Basin

also the evaluation of the anomalies (expressed in percentage) of the analysed events, from which their return periods can be evaluated.

Surfer 8 was the software used for the maps confection with the isolines of the data series– precipitation, soil water surpluses and their anomalies. The used scales for the isolines have been: precipitation = 5 mm; soil water surpluses = 20 mm and anomalies = 10% respectively.

The Buenos Aires province has been divided in 13 sectors (shown in Figure 3 and listed in Table 2) according to its sub-basins (as suggested in National Water Resources, 2002) in order to assess with a larger detail, the fields of the mean precipitation and the soil water surplus throughout the province area.

Table 2
Sectors Studied of Buenos Aires Province Shown in Figure 3

Sector	*Name*
1	Northeastern stream basins
2	Arrecifes River basin
3	Northwestern area of the Salado River basin
4	Central area of the Salado River basin
5	Salado River mouth
6	Drainage basin of the La Plata River at the South of the Samborombon River
7	Region without surface drainage
8	Southern area of the Salado River basin
9	Channels area at the South of the Salado River
10	Lagoon area at the Southwest
11	Basins and Streams at South
12	Southeastern basin and streams
13	Small rivers and streams with the Atlantic drainage

The field maps of annual and monthly precipitation and soil water surplus are realized, obtaining mean values for each sector of the province.

3. RESULTS AND DISCUSSIONS

Table 3 shows the bimonthly MEI (multivariate ENSO index) of the ENSO phases derived from the terciles of the MEI rankings (Wolter, 2007) during the studied period (from December 1999–January 2000 to November–December 2002). Since the floods occurred in March 2001 and March 2002, it is evident that they Can not be ascribed to the ENSO events as results of heavy rains, because in those periods the MEI was corresponding to Neutral events.

Table 3
Bimonthly ENSO Phases of Years 2000, 2001 and 2002 (*N*: Neutral, *A*: La Niña, *O*: El Niño)

Year	*Bimonthly ENSO phases*											
	D-J	*J-F*	*F-M*	*M-A*	*A-M*	*M-J*	*J-J*	*J-A*	*A-S*	*S-O*	*O-N*	*N-D*
2000	A	A	A	N	N	N	N	N	N	N	A	A
2001	N	A	A	N	N	N	N	N	N	N	N	N
2002	N	N	N	O	O	O	O	O	O	O	O	O

The results presented in the following Tables (4-7) show the mean values of the precipitations and of their anomalies evaluated in each sector of Table 2 and referring to different periods.

Table 4 presents the cumulated annual precipitation and their anomalies in the years 2000, 2001 and 2002.

Table 4
Annual Cumulated Precipitations (in mm) and their Respective Anomalies (Expressed in %) Recorded in the Years 2000 (Columns A and B, Respectively), 2001 (C and D) and 2002 (E and F) in the Different Sectors of the Buenos Aires Province

Sector	*A*	*B*	*C*	*D*	*E*	*F*
1	1,300	**85**	1,500	**90**	1,400	**95**
2	1,300	**80**	1,400	**80**	1,400	**90**
3	1,100	**70**	1,400	**90**	1,200	**90**
4	1,100	**64**	1,450	**90**	1,450	**95**
5	1,050	**70**	1,250	**85**	1,400	**95**
6	1,200	**80**	1,350	**90**	1,450	**95**
7	1,000	**70**	1,250	**90**	1,150	**85**
8	1,000	**70**	1,150	**85**	1,200	**90**
9	1,050	**65**	1,200	**85**	1,350	**95**
10	900	**50**	1,100	**85**	850	**65**
11	900	**65**	1,150	**95**	1,150	**90**
12	1,050	**80**	1,200	**90**	1,300	**95**
13	600	**65**	800	**90**	600	**60**

From these data it is evident that Sector 10, is the only area showing an anomaly of 50% in the precipitations of the year 2000 (which means that the return period is 50 years in a century). On the contrary, all the anomalies in the precipitations for the year 2001 vary between 85% and 90%, meaning that, in the 85-90% of the years, the precipitation will be lower or equal than the value recorded in the 2001. The anomalies of precipitation in the year 2002 in sectors 10 and 13, are 65% and 60%, respectively, while the other sectors show anomalies varying between 90 and 95%.

Table 5 reports, for each sector, the monthly cumulated precipitation and its corresponding anomaly, recorded during the months in which the biggest precipitation amounts have been observed: October 2000, March 2001, October 2001 and March 2002.

Table 5 presents highly positive anomalies of precipitation that, in some cases, are very high, especially during March 2002. In some cases, an anomaly of 99% has been evaluated, and this fact indicates that such values of precipitation can be observed in every year of a century. Moreover, we can see as the precipitations observed during October 2000 and March 2001 are lower than the normal values only in Sector 13.

Table 6 shows the annual soil water surpluses observed in the years 2000, 2001, 2002, and their respective anomalies.

Table 5
Cumulated Precipitations (in mm) and their Respective Anomalies (Expressed in %) Recorded in the Months: October 2000 (Columns A and B, Respectively), March 2001 (C and D), October 2001 (E and F) and March 2002 (G and H)

Sector	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
1	200	**85**	200	**75**	250	**95**	300	**90**
2	150	**70**	200	**70**	220	**95**	300	**85**
3	200	**90**	250	**90**	200	**90**	350	**85**
4	200	**85**	220	**80**	220	**95**	400	**95**
5	150	**75**	170	**80**	200	**90**	300	**99**
6	150	**75**	200	**90**	180	**90**	300	**99**
7	200	**65**	250	**90**	150	**75**	250	**85**
8	200	**95**	200	**85**	150	**70**	350	**90**
9	150	**80**	100	**65**	150	**75**	300	**99**
10	200	**85**	150	**80**	200	**80**	150	**50**
11	150	**80**	100	**65**	150	**85**	120	**70**
12	100	**60**	100	**60**	150	**85**	250	**85**
13	50	**55**	75	**60**	75	**85**	50	**40**

Table 6
Annual Soil Water Surpluses (in mm) and their Respective Anomalies (Expressed in %) Recorded in the Years 2000 (Columns A and B, Respectively), 2001 (C and D) and 2002 (E and F)

Sector	*A*	*B*	*C*	*D*	*E*	*F*
1	500	**90**	500	**90**	500	**90**
2	500	**80**	500	**80**	500	**90**
3	350	**85**	400	**90**	350	**85**
4	400	**75**	500	**90**	550	**90**
5	350	**70**	400	**80**	600	**95**
6	550	**85**	400	**80**	600	**95**
7	250	**80**	300	**90**	200	**80**
8	300	**75**	350	**85**	400	**90**
9	250	**65**	350	**80**	600	**97**
10	150	**50**	300	**80**	150	**60**
11	200	**60**	300	**95**	400	**95**
12	250	**70**	300	**85**	600	**97**
13	50	**70**	80	**85**	80	**70**

It can be seen that sectors 3, 7, 10 and 13 of western region present a decrease in values corresponding to year 2002 respecting those of 2001. Instead, sectors 2, 4, 5, 6, 8, 9, and 12 of the center-eastern area of the province had an increase in values of 2002 respecting 2001 while sectors 1 and 11 were stables.

Table 7, Presents the cumulated monthly soil water surpluses and their respective anomalies of the main months in which the largest precipitations have been observed: October 2000, March 2001, October 2001 and March 2002 for each sector shown in Table 2.

Table 7
Cumulated Monthly Surpluses of Soil Water (in mm) and their Respective Anomalies (Expressed in %) Recorded in the Months: October 2000 (Columns A and B, Respectively), March 2001 (C and D), October 2001 (E and F) and March 2002 (G and H)

Sector	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
1	40	**82**	120	**80**	160	**97**	100	**85**
2	40	**70**	80	**75**	140	**97**	100	**90**
3	30	**85**	160	**92**	140	**97**	150	**85**
4	50	**77**	160	**90**	140	**97**	250	**97**
5	50	**77**	100	**90**	100	**85**	200	**99**
6	40	**77**	120	**95**	100	**90**	200	**97**
7	50	**85**	120	**95**	40	**80**	100	**80**
8	100	**95**	100	**90**	60	**80**	150	**90**
9	60	**80**	20	**85**	60	**85**	200	**95**
10	60	**87**	60	**92**	100	**85**	5	**65**
11	60	**90**	40	**92**	40	**90**	40	**90**
12	20	**60**	10	**80**	80	**90**	100	**85**
13	0	**95**	10	**90**	20	**99**	0	**80**

All sectors show positive anomalies with very high percentages, meaning that the observed precipitation regime can be classified as statistically unusual. These tables allow to evaluate the probabilities of occurrence (and from these data the return times) of similar precipitation amounts in the future.

Figure 4, shows the maximum values of the soil water surpluses and their year of occurrence for all the sectors analysed. It can be seen that the values referring to the sectors 2, 4, 7, 10 and 13 were observed in both years 2001 and 2002.

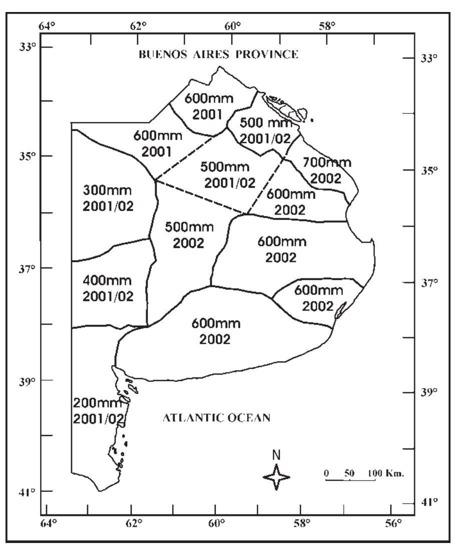

Figure 4: Maximums Soil Water Surpluses and their Year of Occurrence

Figure 5, is added to this study because here it can be seen three stations of the more affected area by the flood (Junín, Nueve de Julio and General Villegas), the depth of water table from 1998 to 2004, according measures of March of every year (source: Argentine Crops Gatherers Federation). The flood of 2000–2002 began with water table at low depth and during the event they reached a minimum value.

Since 2003-2004, a generalized profoundness of the water table depth is observed. This continues now and after the studied event there are no more floods, by the contrary year 2008 and the first four months of 2009 were very dry years. It can be said that the whole province is suffering an important drought. At the same time, cold phases of ENSO (La Niña) at the equatorial Pacific have alternated and ultimately neutral phases.

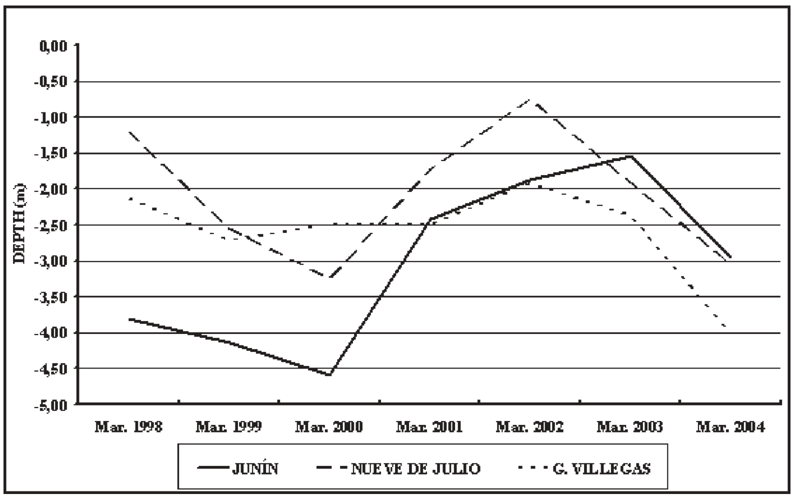

Figure 5: Depth of the Water Table (m)

4. CONCLUSION

Climate variability is a source of risk and, which determines the allocation of resources and technology. Without doubt, the ability to predict the most dangerous weather conditions would improve the management of human activities, reducing the negative effects and enhancing the capacity of taking advantage of the favorable scenarios. In this respect, make the diagnosis of the hazardous weather could led to satisfy the requirements of different types of activities and focusing on the regions of interest.

It is essential that the responsible for the political decisions who aim, at preserving the welfare of a region are well informed about: i) the climate of the region, ii) how the climate can change, and iii) what is the uncertainty associated with the future projections.

Specifically, the main conclusions of this work are that the anomalies of the annual precipitations have been very high in Buenos Aires province during the two years 2001 and 2002, with the only exception of the sectors 7, 10, 11 and 13 when compared with the values of a reference period of 40 years.

Concerning the soil water surpluses in the Buenos Aires province, the year 2001 presents higher anomalies than the 2000. During the 2002, the sectors 2, 5, 6, 8, 9 and 12 show higher anomalies values than the previous two years. The anomalies of soil water surpluses exceeded the 80% in almost the whole province.

This event was a very rare episode that could occur again. Although it has been demonstrated that, in the Buenos Aires province, there is a positive correlation between the El Niño phase of ENSO and the occurrence of heavy rainfalls, in the analysed floods it was evident that the main part of the event took place during Neutral conditions and even, during the cold phase, (La Niña) of ENSO. In fact, the El Niño phase appeared after the flood event, and its the causes need to be sought in oceanic and atmospheric anomalies of other variables.

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