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Validation of meteorological series and estimation of climate change indicators in agricultural locations from Uruguay

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Abstract

Evidence of climate change is not easily detectable, however, by monitoring indicators of climate extremes, a first approximation is possible. For this study, trends of 25 indicators of climatic extremes and maximum and minimum temperatures were estimated by means of least squares regression of daily meteorological series of 5 stations from Uruguay, previously validated by descriptive analysis, quality control and homogeneity detection. The results revealed that the series have good quality, but required homogenization, with the exception of the La Estanzuela precipitation series. Significant positive trends indicate, in Las Brujas, increase in consecutive wet days (CWD), warm days (TX90p), and mean maximum and minimum temperatures. In Salto grande, increase in heavy precipitation days (R20), summer days (SU25), tropical days (TR20) and warm nights (TN90p), and mean maximum and minimum temperatures. In La Estanzuela, increase in the minimum monthly value of daily minimum temperature (TNn) and in the mean minimum temperatures. In Tacuarembó, increase in consecutive wet days (CWD), in tropical nights (TR20) and warm nights (TN90p), and in mean minimum temperatures. In Treinta y tres, increase in tropical nights (TR20), warm nights (TN90p) and in mean maximum temperatures. On the other hand, the significant negative trends imply, in Las Brujas, decrease in the days of frost (FD0), in the maximum monthly value of maximum daily temperature (TNx) and in the cold nights (TN10p). In La Estanzuela, decrease in cold nights (TN10p) and cold days (TX10p). In Salto grande, decrease in the cold nights (TN10p) and in the diurnal temperature range (DTR). In Tacuarembó, decrease in simple daily intensity (SDII) and in consecutive dry days (CDD) and in Treinta y tres, decrease in cold days (TX10p).

Key words: climate change, indicators, series, station, precipitation, temperature.

Resumen

Las evidencias del cambio climático no son fácilmente detectables, no obstante, mediante el monitoreo de indicadores de extremos climáticos, es posible una primera aproximación. Para este estudio, se estimaron las tendencias de 25 indicadores de extremos climáticos y de las temperaturas máximas y mínimas, mediante regresión de mínimos cuadrados de series meteorológicas diarias de 5 estaciones de Uruguay, validadas previamente mediante análisis descriptivos, control de calidad y detección de homogeneidad. Los resultados revelaron que las series presentan buena calidad, pero requirieron homogenización, a excepción de la serie de precipitación de La Estanzuela. Las tendencias positivas significativas indican, en Las Brujas, un aumento en los días húmedos consecutivos (CWD), días cálidos (TX90p), y en las temperaturas máximas y mínimas medias. En Salto grande, aumento en la precipitación diaria muy intensa (R20), en los días de verano (SU25), noches tropicales (TR20) y cálidas (TN90p), y temperaturas máximas y mínimas medias. En La Estanzuela, aumento en los mínimos de temperatura mínima (TNn) y en las temperaturas mínimas medias. En Tacuarembó, aumento en los días húmedos consecutivos (CWD), en las noches tropicales (TR20) y cálidas (TN90p), y en las temperaturas mínimas medias. En Treinta y tres, aumento en las noches tropicales (TR20) y cálidas (TN90p) y en las temperaturas máximas medias. Por su parte,

las tendencias negativas significativas implican, en Las Brujas, disminución en los días de heladas (FD0), en los máximos de temperatura mínima (TNx) y en las noches frías (TN10p). En Salto grande, disminución de las noches frías (TN10p) y en el rango diurno de temperatura (DTR). En La Estanzuela, disminución en las noches (TN10p) y días fríos (TX10p). En Tacuarembó, disminución en la intensidad diaria simple (SDII) y en los días secos consecutivos (CDD) y en Treinta y tres, disminución en los días fríos (TX10p).
Palabras clave: *cambio climático, indicadores, series, estación, precipitación, temperatura.*

1. Introduction

Climate change is undoubtedly one of the most important problems facing the planet, since it highlights the fragility of the environment in the face of alteration and/or modification of the natural behavior of meteorological variables and the direct consequences of this phenomenon on humanity. Much research confirms that global climate change is a fact and has intensified in recent years, with detrimental effects on the environment, the economy, agriculture and societies around the world (IPCC, 2014). That is why it is increasingly important to carry out studies that can detect and monitor signs of change in meteorological variables and that appropriate and timely adaptation measures can be developed for this eventuality.

However, it is not always possible to confirm the signs of change in the meteorological variables for a particular locality due to the enormous temporal and spatial variability of some of these elements. Therefore, the team of experts of CCl/CLIVAR for "Climate Change Detection Monitoring and Índices" (ETCCDMI) developed 27 indices called climate extremes indicators, based on daily records of temperature and rainfall. These variables are considered those that respond more quickly to the influence of climate change. The indicators have been grouped in the computational tool RClimDex (Zhang and Yang, 2004), which is developed under the programming R language.

These indicators of climate extremes are used to detect events with a low probability of occurrence, and their application has been able to detect significant trends in these events, reaffirming the theory of climate change. Among the most recent studies are the works of Pinilla and Pinzón (2012), Meira de Souza and Vieira de Azevedo (2012), Sensoy *et al.* (2013), Jun *et al.* (2016), Badsha *et al.* (2016), Hidayat *et al.* (2018) and Atcheremi *et al.* (2018), whose results demonstrate a high variability of the indicators.

A fundamental requirement for the use of climate change indicators is the management of daily databases, of appropriate length, quality and homogeneity, which has limited their applicability, since the disposition of records under such characteristics is not always possible. On the other hand, the detection of trends that indicate lack of homogeneity in a climatological series is usually attributed to measurement errors, station movements, measurer changes, among other reasons (OMM, 2011). Therefore, it is necessary to apply quality control methodologies and homogenization processes to determine the viability of the available climatic series and to confirm that the trends detected in the homogeneous series are attributed to climate change (IPCC, 1992, 1995, 2001, 2007, 2013 y 2014).

Uruguay is a country that, due to its geographical location and exports, is highly dependent on agricultural and livestock production (Inda and Mazzeo, 2012), and is especially vulnerable to changes in the climate. The most notorious examples are the impacts generated by extreme events in Uruguayan territory at the end of the 20^{th} century and the first decade of the 21st century that produced great economic losses. An example of this are the droughts of 1999-2000 and those of 2008-2009 whose losses were estimated to be between 200 and 250 million dollars (Barrenechea, 2009), late frosts in 2008 that affected thousands of vineyards, or excess water, occurred in the years 2000 and 2001 that greatly affected wheat, barley and peach crops (Gimenez and Lanfranco, 2009).

Therefore, this study aimed to detect signs of climate change by applying the climatic extremes indicators to daily series of temperature and precipitation from 5 agrometeorological stations belonging to the

National Institute of Agricultural Research of Uruguay located in sectors agricultural of national interest, which were previously subjected to quality control processes and homogeneity detection.

2. Data and methods

2.1. Meteorological data

The accumulated precipitation, maximum temperature and minimum daily temperature bases of five stations belonging to the National Institute of Agricultural Research of Uruguay were used (Table 1 and Figure 1). The recording of these stations was adjusted to a common period from 1980 to 2019, with the exception of the maximum and minimum daily temperature of the Tacuarembó station, whose recording started in 1986.

Table 1: Data from INIA Uruguay agrometeorological stations. (Source: http://www.inia.uy/)

Name	Latitude	Longitude	Altitude (m.a.s.l.)
La Estanzuela	34° 20’	57° 41’	81
Las Brujas	34° 40’	56° 20’	32
Salto grande	31° 16’	57° 53’	50
Tacuarembó	31° 42’	55° 49’	140
Treinta y tres	33° 14’	54° 15’	100

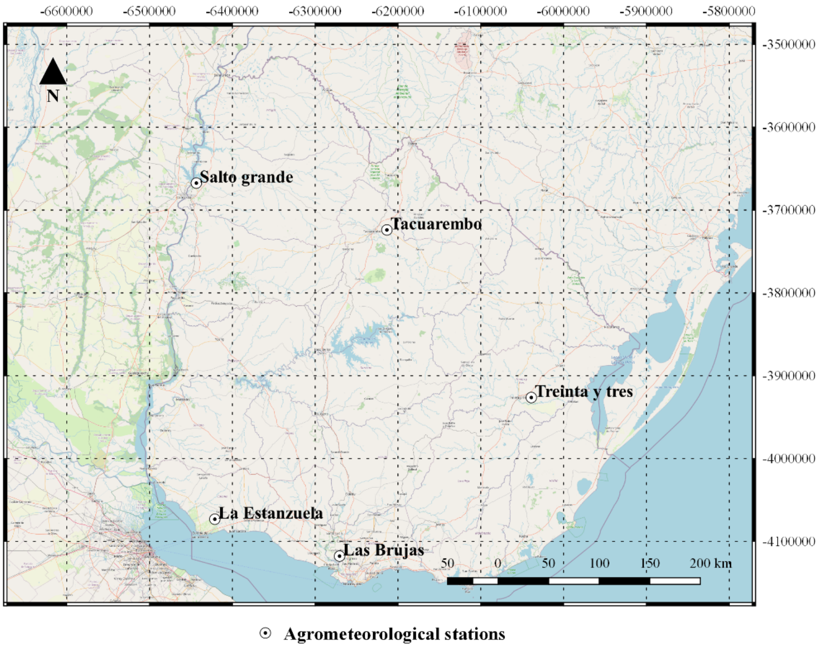

Fig. 1: Geographical location of the agrometeorological stations belonging to INIA Uruguay.

The records of these stations are available in the agrometeorological data bank of the portal http://www.inia.uy/gras/Clima/Banco-datos-agroclimatico. These stations are located in sectors of great agroproductive importance for Uruguay, thanks to their role in generating technology for agricultural-livestock, dairy and fattening production systems (La Estanzuela), fruit growing, rice, horticulture, citrus production, pastures and forages, environmental and forest sustainability (Salto grande, Las Brujas, Treinta y tres), animal production of wool and bovine and ovine meat in extensive and semi-extensive systems, improved and adapted forage varieties, horticultural crops and rice (Tacuarembó).

2.2. Quality control of meteorological series

All meteorological series must have the quality requirements so that they can be considered valid for their use. However, the quality control procedures in a climatic series must be applied with reservations especially to daily precipitation, since their records come from highly dynamic and chaotic processes. Therefore, for this investigation it was decided to apply the following quality control criteria to the meteorological series using the RClimTool (Herrera, 2014) tool:

- A descriptive analysis consisting of the calculation of the number of data (n), maximum (Max) and minimum (Min) value, mean, variance, standard deviation (Std. Dev), median and coefficient of variation (CV %).
- For the maximum and minimum daily temperature, the following quality control criteria based on percentages were applied:
  - Outliers within the interval $\bar{x} \pm 4s$, where $\bar{x}$ is the sample mean and s is the standard deviation.
  - Data recorded where the maximum temperature is less than the minimum temperature of the day.
  - Days in which the variation of a temperature data with respect to the previous one was greater than or equal to 10 °C.
  - Equal data in a period greater than five consecutive days.
- For the precipitation, it was decided to apply the elimination of negative values with the RClimdex tool as a valid quality criterion.
- Analysis of homogeneity with the following absolute tests, for a significance level of 0.05:
  - Contrast of normality using the Kolmogorov-Smirnov test.
  - Trend detection through the Mann-Kendall test.
  - Detection of variance stability using the Siegel Tukey test.
  - Detection of the stability of the mean using the U Mann-Whiney test.

The results of the statistics were grouped by meteorological variable and station, specifying the resulting p-value and the decision criteria for each test. In cases where inhomogeneities were detected in the series, they were corrected using the R climatol package (Guijarro, 2018).

2.3. Estimation of climate change indicators

Once the meteorological series were validated, the estimation of 25 indicators out of the 27 proposed by the Expert Group on Detection and Indices of Climate Change (ETCCDI) was carried out using the RClimdex computer tool. Table 2 shows the precipitation-based indicators and Table 3 shows the temperature-based indicators chosen for the study. Additionally, trends in mean maximum and minimum temperatures were estimated. These indicators were chosen taking into account the relevance they represent for the local climate and their interest for potential impact studies.

Once the indicators were calculated, the Rclimdex tool generated tables of the results in csv format and generated annual series plots along with their trends estimated by least squares regression and by weighted linear regression model. The regression adjustment statistic corresponded to the determination coefficient (R^2) with its respective estimated p-value at a confidence level of 95%. Likewise, the plots also illustrate the slope and its error. The estimation of the slope made it possible to determine the increase or decrease in the unit of the extreme climate indicator at the end of the period used.

Table 2: Description of climatic extremes indicators based on temperature selected for the study (Zhang and Yang, 2004).

ID	Indicator	Definition	Unit
FD0	Frost days	Number of days in a year when TN (daily minimum) < 0 °C	Days
SU25	Summer days	Number of days in a year when TX (daily maximum) > 25 °C	Days
TR20	Tropical nights	Number of days in a year when TN (daily minimum) > 20 °C	Days
GSL	Growing season length	Annual (1^{st} January to 31^{st} December in NH, 1^{st} July to 30^{th} June in SH) counts between the first period of at least 6 days with TG > 5 °C and the first period after July 1 (1^{st} January in SH) 6 days with TG < 5 °C	Days
TXx	Max Tmax	Maximum monthly value of maximum daily temperature	°C
TNx	Max Tmin	Maximum monthly value of minimum daily temperature	°C
TXn	Min Tmax	Minimum monthly value of maximum daily temperature	°C
TNn	Min Tmin	Minimum monthly value of daily minimum temperature	°C
TN10p	Cool nights	Percentage of days when TN (daily minimum) $<$ 10^{th} percentile	Days
TX10p	Cool days	Percentage of days when TX (daily maximum) $<$ 10^{th} percentile	Days
TN90p	Warm nights	Percentage of days when TN (daily minimum) $>$ 90^{th} percentile	Days
TX90p	Warm days	Percentage of days when TX (daily maximum) $>$ 90^{th} percentile	Days
WSDI	Warm spell duration	Annual count of days with at least 6 consecutive days when TX (daily maximum) $> 90^{th}$ percentile	Days
CSDI	Cold spell duration	Annual count of days with at least 6 consecutive days when TN (daily minimum) $< 10^{th}$ percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX (daily maximum) and TN (daily minimum)	°C

Table 3: Description of climatic extremes indicators based on rainfall selected for the study (Zhang and Yang, 2004).

ID	Name of Indicator	Definition	Unit
SDII	Simple daily intensity index	Total annual precipitation divided by the number of wet days (defined by precipitation ≥ 1.0 mm) in a year	mm/ day
R10	Number of heavy precipitation days	Number of days in a year when precipitation ≥ 10 mm	Days
R20	Number of very heavy precipitation days	Number of days in a year when precipitation ≥ 20 mm	Days

ID	Name of Indicator	Definition	Unit
CDD	Consecutive dry days	Maximum number of consecutive days with RR (daily amount of precipitation) $<$ 1 mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR (daily amount of precipitation) $\geq$ 1 mm	Days
R95p	Very wet days	Total annual precipitation at which RR (daily amount of precipitation) $>$ 95 percentile	mm
R99p	Extremely wet days	Total annual precipitation at which RR (daily amount of precipitation) $>$ 99 percentile	mm
PRCPTOT	Annual total wet-day	Total annual precipitation on wet days (RR (daily amount of precipitation) $\geq$ 1 mm)	mm
Rx1day	Max 1-day precipitation amount	Maximum monthly precipitation in 1 day	mm
Rx5day	Max 5-day precipitation amount	Maximum monthly precipitation on 5 consecutive days	mm

3. Results and discussion

3.1. Quality control of meteorological series

In relation to the first steps in the quality control of the meteorological series, Table 4 shows the results of the descriptive analysis. The precipitation presented values from 0 to a maximum of 255 mm for the La Estanzuela, 183 mm in Las Brujas, 258 mm in Salto grande, 193 mm in Tacuarembó and 208 mm in Treinta y tres. These maximum daily precipitation values can be considered very unlikely. Recent studies confirm these amounts for return period of daily rainfall greater than 50 years in Uruguay (Koolhaas, 2019), which implies that despite their low probability, they should be considered in studies based on climatic extremes. On the other hand, even when the complete metadata of the station is available, there are precipitation values that although they may seem suspicious, it is not possible to determine that they are completely erroneous, since all the data may be valid, due to the complex processes that originate precipitation (Rustemeier *et al.*, 2011). These amounts originated a high variance and therefore a high coefficient of variation, characteristic of the behavior of precipitation. The mean and median rainfall did not coincide in any of the stations. Regarding temperatures, the means and medians were close to each other, with low coefficients of variation compared to the coefficients of variation of precipitation.

Quality control results are found in Table 5. There was no negative record of precipitation. Regarding the maximum and minimum temperature, the percentages of each quality control criterion were less than 3.15 % in all the stations, which represents a tolerable level of missing data according to WMO (2011) for subsequent climatic analyzes.

Regarding homogeneity, the results of the Kolmogorov-Smirnov test (Table 6) revealed that none of the series of stations follow a normal distribution, so the non-parametric tests used in the other homogeneity analyzes were the ideal ones. Precipitation turned out to be homogeneous only in La Estanzuela, recording levels of significance above the p-value 0.05 that was used to apply the tests, thus rejecting the null hypothesis. For the others stations, p-values both higher and lower than the significance level were presented in the applied tests, which meant presence of trend, non-stable variances, different means and therefore, lack of homogeneity.

The lack of homogeneity in a meteorological series can hinder its long-term usefulness, since it does not guarantee that its internal changes are due to natural climatic variations (Aguilar *et al.*, 2003). This can mask the true climate signal and compromise the reliability and robustness of any assessment. In these cases, the homogenization of the series is recommended (Brunetti *et al.*, 2012; Ribeiro *et al.*, 2016). Therefore, all series were homogenized with the climatol R package (Guijarro, 2018).

Table 4: Result of the descriptive analysis of the maximum, minimum temperatures and precipitation series for the five agrometeorological stations.

Variable	Statistic	Agrometeorological station La Estanzuela	Las Brujas	Salto grande	Tacuarembó	Treinta y tres
Precipitation	n	14610	14610	14610	14610	14610
	Min.	0	0	0	0	0
	Max.	255	183	258	193	208
	Mean	3.161	3.227	3.793	4.139	3.736
	Variance	109.321	110.622	162.727	169.072	134.768
	Std. Dev.	10.456	10.518	12.756	13.003	11.609
	Median	0	0	0	0	0
	CV %	330.771	325.928	336.316	314.152	310.732
Maximum temperature	n	14610	14610	14610	12145	14610
	Min.	5.5	6	4.9	0	6.4
	Max.	39.8	39	40.2	39.4	40.4
	Mean	21.798	22.006	24.607	22.909	22.891
	Variance	40.082	39.099	40.025	38.119	34.286
	Std. Dev.	6.331	6.253	6.327	6.174	5.855
	Median	21.85	22	24.9	23.2	23
	CV %	29.044	28.415	25.71	26.95	25.58
Minimum temperature	n	14610	14610	14610	12145	14610
	Min.	-3	-4.2	-5.8	-6.3	-5.5
	Max.	26.7	25.3	29	26.2	26.7
	Mean	11.929	11.347	13.14	11.955	11.136
	Variance	28.458	29.261	36.003	32.198	34.557
	Std. Dev.	5.335	5.409	6	5.674	5.879
	Median	12.1	11.6	13.8	12.6	11.4
	CV %	44.72	47.672	45.664	47.464	52.788

Table 5: Quality control results of the precipitation, maximum and minimum temperatures series for each agrometeorological station.

Variable	Criterio (%)	Agrometeorological station La Estanzuela	Las Brujas	Salto grande	Tacuarembó	Treinta y tres
Precipitation	Negative values	0	0	0	0	0
Maximum temperature	Atypical values	0	0	0.02	0.02	0
	Values tmax<tmin	0	0	0	0	0
	Variation values > 10	2.41	2.66	2.46	3.15	2.33
	Consecutive values	0	0	0	0	0
	Total values NA	0	0	0	0	0
Minimum temperature	Atypical values	0	0	0.01	0.01	0
	Variation values > 10	2.41	2.66	2.46	2.62	2.33
	Consecutive values	0	0	0	0	0
	Total values NA	0	0	0	0	0

No break-point was detected by that package in the precipitation and maximum temperature series, so only missing data were filled in during the process. On the other hand, single break-points were found at monthly scale in Las Brujas, Salto grande and Tacuarembó. However, the only clear break-point in the daily series was that of Salto grande. Therefore, taking a conservative approach, only this series was adjusted during the process. Figure 2a shows a local decreasing trend in the nineties which the package resolves as a break-point in July 14^{th} 1993. The upper part of Figure 2b displays the adjusted series from the first (in green) and last (in red) homogeneous subperiods, while the corrections applied appear in the lower part, showing seasonally varying corrections between 0 and 1.2 °C.

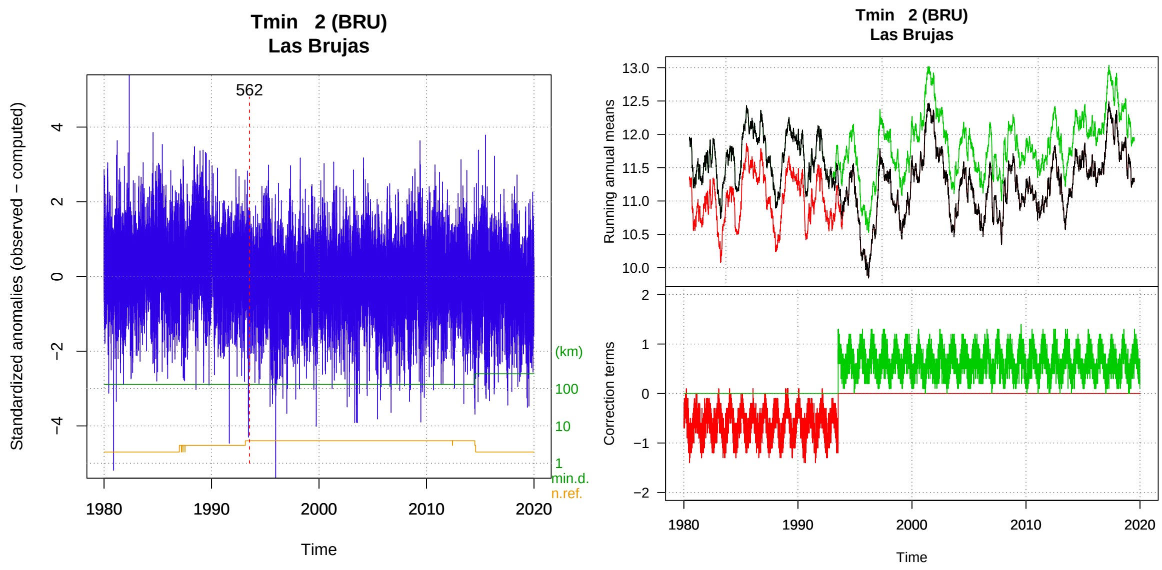

Fig. 2: Left: Detection of a change in the mean of the series of Las Brujas. Right: The upper part shows the running annual means of the original series (in black) and of the adjustments from the two homogeneous sub-periods, while the lower part displays the corrections applied for the adjustments.

3.2. Climate change indicators

With the homogenized series, the climate change indicators were calculated. The results of the estimation of climate change indicators based on their coefficient of determination, p-value and slope, are found in Tables 7 and 8. It can be seen that the coefficients of determination did not exceed 33 % of adjustment, but according to their p-value, some showed statistical significance (highlighted in the table). Despite the fact that the coefficients of determination are not very high, the p-values below the significance level reveal that the trend of the predictive variable provides information on the response even though the data points are far from the regression line. This situation can occur in regressions of climatic variables due to the inherent variability of the data.

The results of the regressions in the indicators revealed both positive and negative trends, that is, increases and decreases in the indicators. By way of illustration, Figure 3 and Figure 4 show plots of the annual series of the indicators of climatic extremes for each station that had the highest coefficient of determination and statistical significance with their adjustment statistics. The indicators based on precipitation (Table 7) were found to be statistically significant in Las Brujas, Salto grande and Tacuarembó. The slopes indicate an increase of 2 days wet consecutive (CWD) in Las Brujas. While, in Salto grande, the days with very heavy precipitation increased by 8 (R20) and in Tacuarembó, there was a decrease of 6 mm in the simple daily intensity (SDII) and 9 consecutive dry days (CDD), and an increase 4 days consecutive wet (CWD).

Daily temperatures-based indicators (Table 8) had higher coefficients of determination at the stations compared to precipitation-based indicators. In La Estanzuela, minimum monthly value of daily minimum temperature (TNn) increased by 2 °C and by 0.6 °C the mean minimum temperatures (TMINx), in contrast, decreased 4 days of cold nights (TN10p) and 3 cold days (TX10p). In Las Brujas, 4 warm days (TX90p), 0.7 °C in the mean maximum temperature (TMAXx) and 0.5 °C in the mean minimum temperatures (TMINx) increased. On the other hand, decreased 9 days of frost (FD0), 1.33 °C in the maximum monthly value of minimum daily temperature (TNx) and 5 days of cold nights (TN10p). In Salto grande, there was an increased 18 days of summer (SU25), 19 days of tropical nights (TR20), 5 days of warm nights (TN90p), 0.6 °C in the mean maximum temperatures (TMAXx) and 1.29 in the mean minimum temperatures (TMINx) , against a decrease of 6 days of cold nights (TN10p) and 0.7 in the diurnal temperature range (DTR).

Table 6: Results of the tests of normality (K-S: Kolmogorov-Smirnov), trend (M-K: Mann-Kendall), stability of the mean (S-G: Siegel-Tukey) and variance (U M-W: U Mann-Whitney) for the five agrometeorological stations.

Variable	Statistic test	Agrometeorological stations									
		La Estanzuela		Las Brujas		Salto grande		Tacuarembó		Treinta y tres	
		P-value	Decision	P-value	Decision	P-value	Decision	P-value	Decision	P-value	Decision
Precipitation	K-S	0	NN	0	NN	0	NN	0	NN	0	NN
	M-K	0.94	NT	0.02	T	0.01	T	0	T	0.22	NT
	S-T	0.28	SV	0	NSV	0	NSV	0	NSV	0.02	NSV
	U M-W	0.28	EM	0	DM	0	DM	0	DM	0.02	DM
Maximum temperature	K-S	0	NN	0	NN	0	NN	0	NN	0	NN
	M-K	0.14	NT	0	T	0.01	T	0.77	NT	0	T
	S-T	0.99	SV	0.68	SV	0.62	SV	0.03	NSV	0.63	SV
	U M-W	0.03	DM	0.01	DM	0	DM	0.87	EM	0	DM
Minimum temperature	K-S	0	NN	0	NN	0	NN	0	NN	0	NN
	M-K	0.01	T	0.01	T	0	T	0	T	0.02	T
	S-T	0.29	SV	0.16	SV	0.19	SV	0.13	SV	0.14	SV
	U M-W	0	DM	0.47	EM	0	DM	0	DM	0	DM

(N: Normality; NN: No normality; T: Trend; NT: No trend; NSV: Non-stable variances; SV: Stable variances; DM: Different means; EM: Equal means.)

In Tacuarembó there was an increase of 9 days of tropical nights (TR20), 5 days of warm nights (TN90p) and 0.7 °C in the mean minimum temperatures (TMIN x). In Treinta y tres, 9 days of tropical nights (TR20), 7 days of warm nights (TN90p) and 0.62 °C in the mean maximum temperatures (TMAXx) increased and 4 cold days (TX10p) decreased.

Table 7: Results of the estimation of climate change indicators based on rainfall according to the R^2 (in %), p-value and trend for the five agrometeorological stations. (Significant values at $\alpha = 0.05$ enhanced in bold.)

	Agrometeorological stations														
	La Estanzuela			Las Brujas			Salto grande			Tacuarembó			Treinta y tres		
ID	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope
SDII	0.2	0.785	0.008	0.4	0.702	-0.011	2.1	0.374	0.035	**21.2**	**0.003**	**-0.149**	0.4	0.683	-0.012
R10	0	0.953	0.006	0.1	0.837	0.021	6.5	0.114	0.166	6.4	0.115	0.189	0.1	0.879	0.017
R20	0	0.951	-0.004	0.1	0.883	0.001	**12.4**	**0.026**	**0.201**	2.6	0.327	0.1	0.4	0.713	-0.027
R25	0.3	0.73	0.013	1.6	0.437	0.043	8.3	0.071	0.139	0.8	0.584	0.046	0.1	0.852	0.012
CDD	3.5	0.251	-0.123	7.9	0.079	-0.129	0.5	0.654	-0.036	**14.8**	**0.014**	**-0.227**	1	0.54	-0.044
CWD	0.8	0.578	0.011	**15.6**	**0.012**	**0.05**	8.2	0.073	0.044	**29.5**	**0**	**0.09**	7.1	0.096	0.038
R95p	0.4	0.707	1.033	4.8	0.174	2.979	0.4	0.715	0.879	0.6	0.64	-1.489	0	0.928	0.222
R99p	2.1	0.37	1.356	3.4	0.253	1.616	2	0.388	1.526	1.1	0.524	-1.005	0	0.923	-0.152
PRCPTOT	0.2	0.798	1.001	2.8	0.302	3.617	6	0.126	7.468	3.5	0.247	6.093	0.1	0.857	0.703
Rx1day	5.5	0.144	0.776	2.8	0.303	0.514	0	0.961	0.028	0.5	0.679	-0.163	0.2	0.807	0.111
Rx5day	3.5	0.25	0.732	0.7	0.614	0.4	1	0.55	0.631	0.5	0.665	-0.358	1.5	0.454	0.564

However, the precipitation-based indicators only presented statistical significance in Salto grande and Tacuarembó and only those related to their intensity, dry and wet days, which allows us to deduce that the changes in rainfall seemed to be more punctual than generalized, in accordance with Gimenez and Lanfranco (2009) on the high temporal and spatial variability of rainfall. The results in estimating precipitation-based climate change indices have demonstrated this same variability in the different studies where they have been applied (Sensoy *et al.*, 2013; Jun *et al.*, 2016; Atcheremi *et al.*, 2018).

Table 8: Results of the estimation of climate change indicators based on temperature according to the R^2 (in %), p-value and trend for the five agrometeorological stations. (Significant values at $\alpha = 0.05$ enhanced in bold.)

	Agrometeorological stations														
	La Estanzuela			Las Brujas			Salto grande			Tacuarembó			Treinta y tres		
ID	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope
FD0	9.3	0.056	-0.055	**33.1**	**0**	**-0.25**	3.6	0.242	-0.058	4	0.215	-0.08	7.7	0.084	-0.132
SU25	4	0.218	0.182	4.3	0.198	0.206	**16.8**	**0.008**	**0.468**	5.5	0.147	0.278	8.1	0.075	0.374
TR20	3.3	0.264	0.107	2.7	0.312	-0.103	**29.1**	**0**	**0.483**	**16.4**	**0.01**	**0.229**	**12.2**	**0.027**	**0.221**
GSL	5.5	0.15	0.056	0	0.948	0.002	1.1	0.527	0.013	2.9	0.3	0.031	3	0.294	0.025
TXx	1.6	0.442	-0.017	0.3	0.719	0.007	0.2	0.773	0.005	1.5	0.454	0.014	0	0.925	-0.002
TNx	4.5	0.19	-0.02	**10**	**0.046**	**-0.034**	8.6	0.065	0.036	1	0.535	0.01	0.4	0.717	0.006
TXn	4	0.218	0.022	1.4	0.471	0.012	2.1	0.37	0.018	0.2	0.758	0.008	2.4	0.336	0.017
TNn	**16.8**	**0.008**	**0.041**	8.6	0.067	0.031	2	0.383	0.018	1.4	0.474	0.016	2.2	0.355	0.016
TN10p	**17.5**	**0.007**	**-0.106**	**25.5**	**0.001**	**-0.12**	**32.5**	**0**	**-0.151**	1.9	0.396	-0.051	1	0.55	0.026
TX10p	**10.1**	**0.045**	**-0.078**	9.3	0.055	-0.068	5.5	0.145	-0.051	1.2	0.496	-0.034	**16.4**	**0.01**	**-0.107**
TN90p	6.4	0.114	0.064	0.9	0.558	0.024	**29.2**	**0**	**0.132**	**13.4**	**0.02**	**0.121**	**22.6**	**0.002**	**0.174**
TX90p	4.3	0.196	0.053	**20.7**	**0.003**	**0.097**	6.3	0.117	0.061	7	0.099	0.078	5.9	0.131	0.065
WSDI	0.1	0.861	0.013	8.4	0.07	0.091	2.1	0.376	0.05	0	0.96	0.003	0.2	0.757	-0.013
CSDI	4.6	0.183	-0.02	-	-	-	2.5	0.326	0.015	1.6	0.441	0.031	0.7	0.597	-0.013
DTR	1.5	0.452	-0.004	1.4	0.468	0.005	13.2	0.021	-0.018	1.1	0.525	-0.006	0.2	0.758	0.003
TMAX x	9.7	0.051	0.012	19.7	0.004	0.018	11.9	0.029	0.015	8.3	0.071	0.013	11.9	0.03	0.016
TMIN x	20.2	0.004	0.016	11.1	0.036	0.014	32.8	0	0.033	10	0.047	0.018	8.6	0.066	0.014

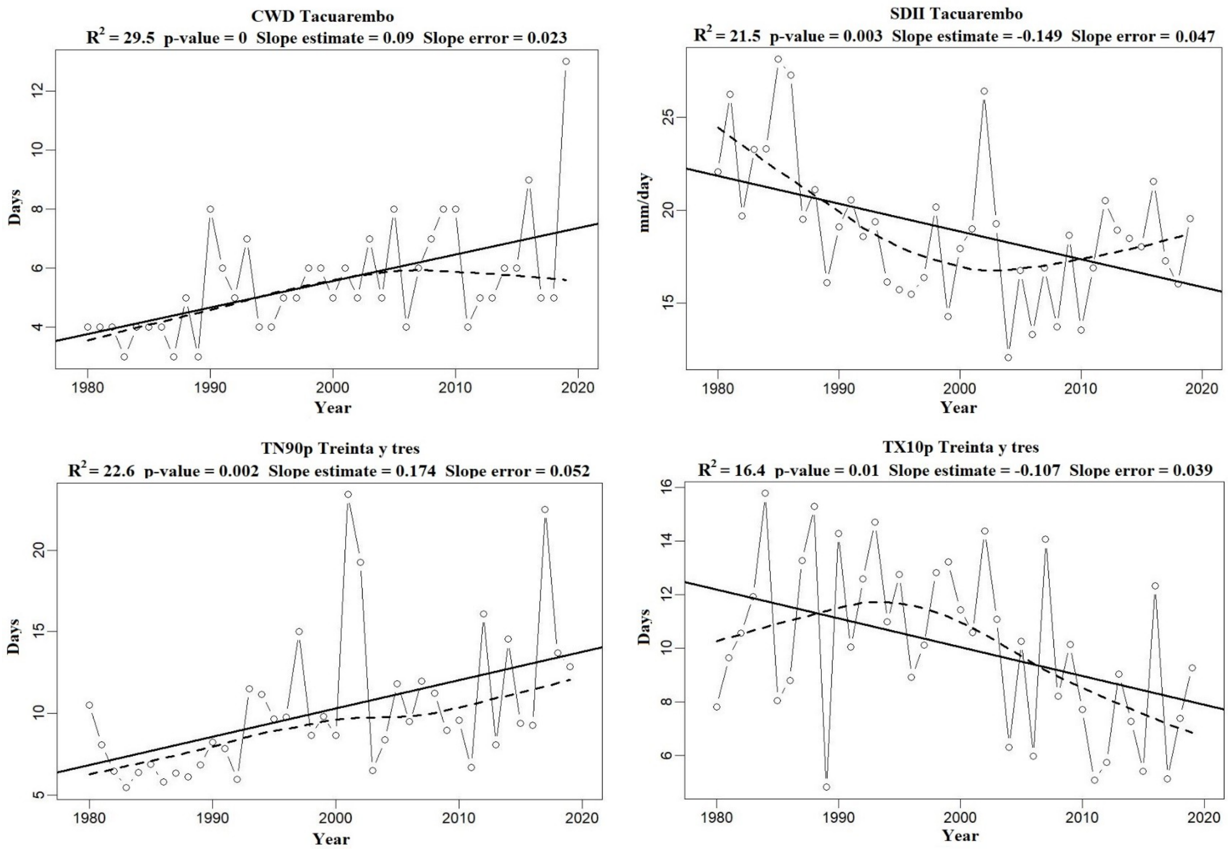

Fig. 3: Plots of the trends in the climatic extremes indicators with the highest coefficient of determination and statistical significance for the Tacuarembó and Treinta y tres stations.

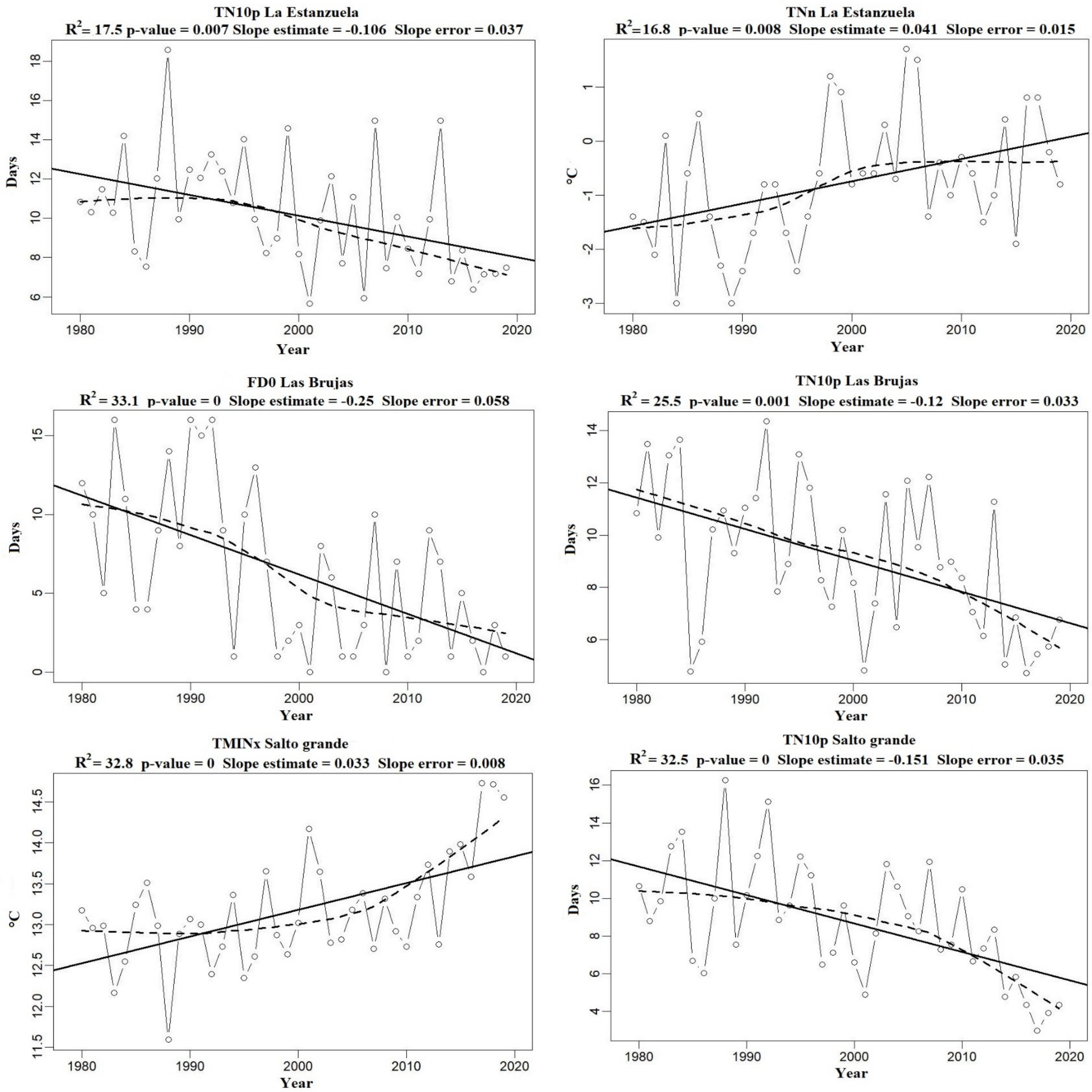

Fig. 4: Plots of the trends of the indices of climatic extremes with the highest coefficient of determination and statistical significance for the La Estanzuela, Las Brujas and Salto grande stations.

The findings found in this study follow the same line of the results of other investigations carried out in Uruguay; An example of this is the work of Giménez *et al.* (2009), Oyhantçábal and Menthol (2009), Renom (2009), Inda and Mazzeo (2012) in relation to the increase in temperatures, confirming the theory about a general increase in this variable worldwide, as stated by the IPCC (2014). Other coincident investigations are those of Renom (2009); Bidegaín *et al.*, (2013) and SNRCC (2014) referring to the increase of warm nights and reduction of cold days and nights. However, the precipitation-based indicators only presented statistical significance in Salto grande and Tacuarembó and only those related to their intensity, dry and wet days, which allows us to deduce that the changes in rainfall seemed to be more punctual than generalized, in accordance with Gimenez and Lanfranco (2009) on the high temporal and spatial variability of rainfall. The results in estimating precipitation-based climate change indices have demonstrated this same variability in the different studies where they have been applied (Sensoy *et al.*, 2013; Jun *et al.*, 2016; Atcheremi *et al.*, 2018).

4. Conclusions

The procedures of quality control of the meteorological series determined that all the stations presented an good quality but inhomogeneity problems.

The indices with the highest positive statistical significance, for all stations, corresponded to those temperatures-based indicators, confirming the influence of climate change on air temperature, as has been seen in other studies worldwide. However, the indicators based on the behavior of rainfall did not show the same trend, so it is not recommended to generalize the possible influence of climate change on this meteorological variable.

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