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Unlocking Weather Observations at Puerto Madryn-Patagonia, Argentina, 1902–1915

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Abstract: The recovery of early records of maximum, minimum, and mean temperatures; pressure; and relative humidity measurements in Puerto Madryn for the period 1902–1915 is presented. A careful evaluation of the quality of the data was performed using internal coherence, tolerance, and temporal consistency tests. The monthly mean series of all the variables, constructed from daily raw data, were subject to several homogeneity tests, and only discontinuities in pressure and relative humidity were found. The homogenized monthly mean series were compared with the Twentieth Century Reanalysis series in annual and seasonal time steps. In addition, the trends of each variable were assessed using the Mann–Kendall procedure, and correlations between relative humidity and the other variables were examined. The results show a remarkably good agreement between the temperature measurements and reanalysis values with a Spearman correlation coefficient of 0.94. The raw data for minimum and maximum temperatures represent a very good upper and lower bound for the mean temperature values of both observational and reanalysis data. Agreement was found to be lower for relative humidity and pressure with the correlation coefficients being close to 0.6 in both cases. No trends were found for the variables. The correlation analysis of the humidity measurements with the other variables shows an inverse dependence of the temperatures and no relatedness with the pressure values.

Keywords: Puerto Madryn; Argentina; data rescue; data homogenization; daily data; quality control

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1. Introduction

In recent decades, considerable efforts have been made to understand climate change and its potential impacts [1]. A plethora of methods have emerged with increasingly higher resolution to provide information on changes in essential climate variables as well as better information to assess the adaptation and risk management [2]. However, uncertainties remain, particularly related to how these changes will be expressed at fine spatial scales, underlining the need for more complete datasets than those currently available [3]. In this sense, historical data, both from proxy archives and instruments, play a key role for the comprehension of climate variability and its long-term change and provide an essential baseline of past climate, which is crucial for both contextualizing and constraining future climate projections [4]. According to the World Meteorological Organization (WMO) [5], long-term instrumental data and metadata from historical instrument observation are essential to preserve and improve our understanding of past climate variability and trends and to support the validation of paleoclimate reconstructions [6].

Early measurements of the atmosphere started at the end of the first half of the 17th century with the invention of the first instruments, although worldwide systematization began around the middle of the 19th century. In South America, it is also possible to find observations dating back to the late 17th century, but they tend to be discontinuous in both spatial and temporal coverage. In addition, the methodology used for the measurements, even until the beginning of the 19th century, was not always systematized and homogenized with different instruments and scales coexisting [7]. In Argentina, the earliest known weather observations date back to 1801 and 1805 (readers can find a hint of the first measurements in Argentina in La Abeja Argentina, 1822 [8]), and many of these weather records in various Argentine cities were maintained since then by scientists, both amateur and professional, doctors, and engineers through personal efforts or organized institutions, such as the Colegio San Carlos, now Colegio Nacional de Buenos Aires. In 1872, the Oficina Meteorológica Argentina (OMA), later transformed into the Servicio Meteorológico Nacional, was established, and following international agreements, the observations were conducted according to the requirements of the International Meteorological Organization (IMO) with instruments mostly acquired and calibrated at Kew Gardens, UK. Most of the observations in the country were focused on mean variables, like temperature, pressure, rain, and relative humidity, and measurements were performed at daily and even sub-daily bases.

Despite their undeniable value, collecting and integrating this heterogeneous mass of information on past weather and climate into current databases are major challenges, as many of these original observations are handwritten with special symbols and stored under different conditions and in different geographical locations. In addition, many of them remain uncatalogued and undigitized, making them difficult to trace [9]. The challenge of assembling historical climate databases has been the focus of many rescue data initiatives in recent years. The Atmospheric Circulation Reconstructions over the Earth (ACRE) (http://www.met-acre.org/ACRE (accessed on 17 October 2023)) initiative is a project dedicated to rescuing early weather records to extend the reanalysis product and includes the early 19th century observations. ACRE has regional chapters in many parts of the world, and Argentina is part of this process through ACRE Argentina.

The present study was developed under the umbrella of ACRE Argentina and is part of a series of climatological studies with weather records from Southern Patagonia during the last decades of the 19th century and the first decades of the 20th century [10]. Patagonia is the southernmost tip of South America, shared by Argentina and Chile, extending from 37° S to Cape Horn at 56° S. This region is the only land mass in an oceanic hemisphere that encounters mid-latitude westerlies, which strongly influence the atmospheric circulation at lower and upper levels and, consequently, the climate of the region [11]. Therefore, understanding its climatology, variability, and evolution prior to present climate change processes can provide insights into the climatology of high southern latitudes and the links to the Antarctic climate.

According to what is published in the Annales of the Oficina Meteorológica Argentina Vol. 3 (1882), the first observations in southern Patagonia date from January 1876, and by 1904, more than 40 weather stations from 23.47° S to 60.73° S were active under the IMO requirements. In the present paper, we introduce rescue data for Puerto Madryn, Chubut Province, Argentina (42°46′ S 65°3′ W) from 1902 to 1915. The variables included correspond to mean, maximum, and minimum temperatures; pressure; and relative humidity values. Since most data rescue efforts have paid more attention to early mean temperature, pressure, and precipitation data but very few of them have considered relative humidity, this study represents the first effort to not only unlock data from Patagonia Argentina but also to include the values of relative measurements. This paper is structured as follows: In Section 2, the data and metadata are briefly reviewed, and the methodology is described, including the quality control procedure for data validation; in Section 3, the results are presented and analyzed; and finally in Section 4, the discussion and conclusions are presented.

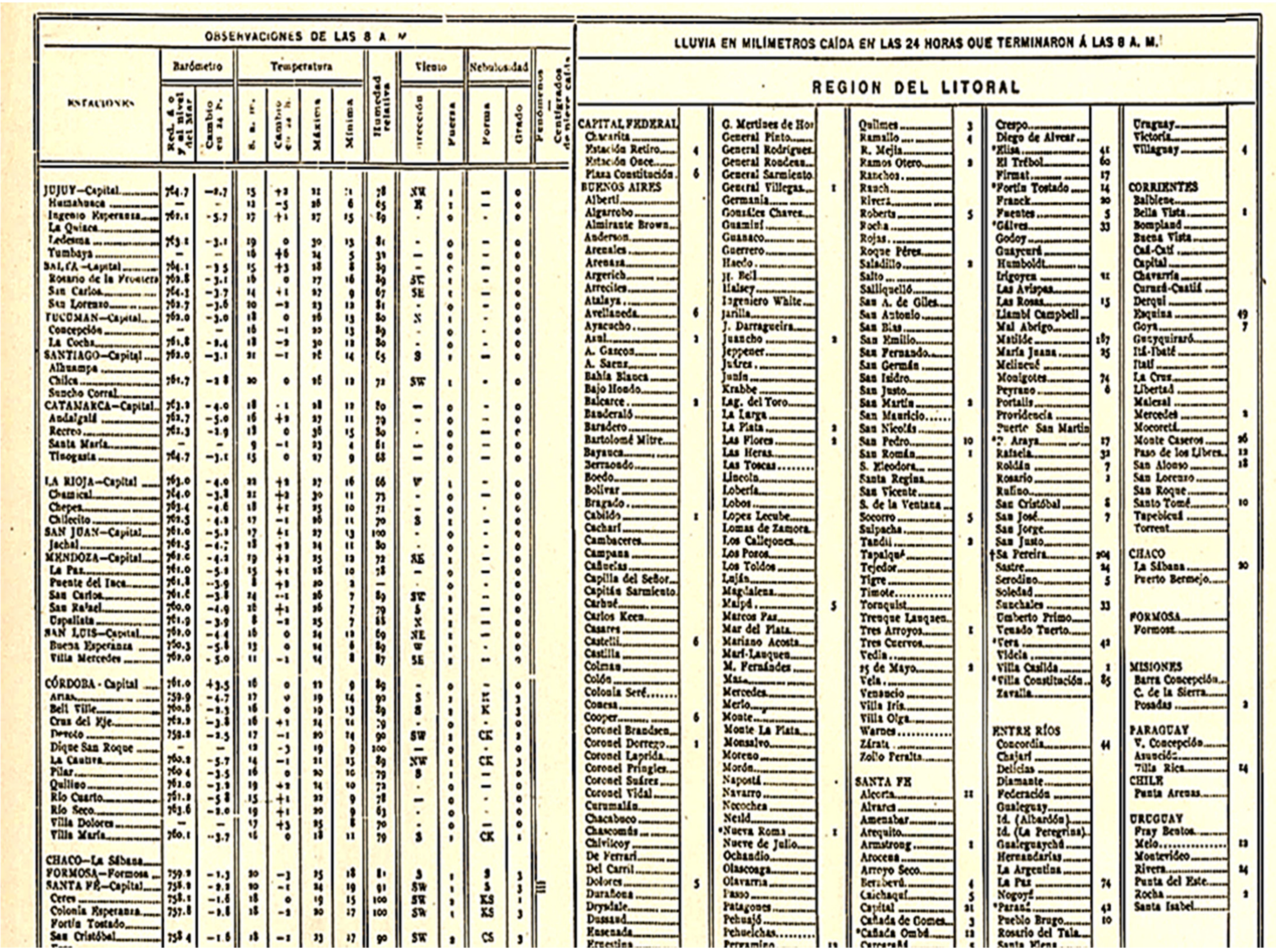
2. Materials and Methods

2.1. Materials

Puerto Madryn (Porth Madryn in Welsh) is a city located on the eastern coast of Patagonia in the province of Chubut (Figure 1). The city is the capital of the Biedma Department. It is set at 42°46′ south and 65°02′ west, 18 m over sea level, on the southwest coast of the Golfo Nuevo, being one of the most important urban settlements of Chubut. The town was founded in 1865 when 150 Welsh immigrants aboard the clipper Mimosa named the port Porth Madryn in honor of Sir Love Jones-Parry, whose estate in Wales was called Madryn. By 1920, Puerto Madryn had only 1222 inhabitants according to the National Institute of Statistics and Census (INDEC; http://www.ferrocarrilesenelconosur.co.uk/01Sbbackground.html (accessed on 17 October 2023)), and at that time, the town consisted of only five houses, a hotel, and three small settlements, corresponding to the national prefecture, the telegraph, and the railway, which makes systematic measurements of significant value.

Figure 1. Puerto Madryn in Argentina. In the upper left corner, the box shows Patagonia Argentina highlighted in black.

The records found in the Annals of the Oficina Meteorológica Nacional are structured as pages divided into two sections, each right and left half corresponding to one day: The main portion being the integrated observations that contain the daily measurements and observations for the 148 measuring stations in the country as well as observations from Brazil, Uruguay, and Chile. The data are composed of daily data at 8 a.m. of the mean, maximum, and minimum temperatures (°C); atmospheric pressure at sea level (mmHg); relative humidity (%); cloudiness; wind; and snow information. The cloudiness values were recorded with an alphanumeric character with one letter representing the cloud type (C: Cirrus, S: Stratus, N: Nimbus, K: Cumulus, and combinations of them) and a number ranging between 0 (clear day) and 3 (cloudy day). The wind values, on the other hand, were recorded by indicating the direction and strength on a numeric scale varying from 0 (calm day) to 4 (hurricane force). The other side contains rainfall data (mm), also for all stations but organized in three main geographic regions: Littoral, Mediterranean, and Patagonian Regions, the last one including Puerto Madryn. The observations also include data from the hydrometric stations and a brief synopsis that includes a forecast for the next 12 h. Figure 2 shows an example of the typical arrangement of data in the publications. It must be noted that the present paper is limited to the analysis of the maximum, minimum, and mean temperature values; pressure; and relative humidity.


OBSERVACIONES DE LAS 8 A. M.

LLUVIA EN MILÍMETROS CAÍDA EN LAS 24 HORAS QUE TERMINARON Á LAS 8 A. M.

REGION DEL LITORAL

Figure 2. Picture of the original page from Annals OMA.

2.2. Methodology

A total of 20,260 meteorological observations were retrieved from the Puerto Madryn dataset, and the digitization process was performed with key entry from the photographed documentary sources. A preliminary assessment of the quality and reliability of the data was performed based on the metadata, the historical information, and a visual inspection of the raw data. As Capozzi et al. [12] pointed out, "a visual inspection of the raw data is a key part of the quality control that highlight some impairments in data quality that would otherwise be very difficult to flag through automatic statistical methods". Unfortunately, there is no information in the metadata on the observers and instruments used in Puerto Madryn; however, some interesting insights related to the Province of Chubut measurements can be found in the Tomo XIV, OMA, for 1901. According to this document, one mercury barometer, two mercury thermometers, a wind vane, and a pluviometer were used. The Fortin barometer was manufactured by Negretti and Zambra as well as the thermometers fixed to a wall in a shed protected from the sun's rays. There is no metadata related to the relative humidity measurements or to the location of the instruments.

The quality of the Puerto Madryn records can be considered as acceptable with most of the printed numbers and letters visible and easy to transcribe; however, a few cases with blurred and/or distorted numbers and letters were found and flagged to check after the digitization process. The WMO [13] recommended the use of quality controls of the climate data set, as erroneous data can affect different aspects of climatic analysis. After the correction of erroneous or missing transcribed data, the daily digitized time series were subjected to a basic quality control. Although there are several techniques for quality control of climate data, there is not a clear system winner or a kind of 'one-size-fits-all', and the combined use of different quality control mechanisms is often effective [14,15]. Thus, the control comprised three basic steps: (1) Tolerance test, i.e., the data of each variable must be within three standard deviations from a mean value; (2) Temporal consistency to check the difference between consecutive daily readings. Following the criteria adopted by Dominguez-Castro et al. [7], values with a difference greater than 10 °C for temperature, 15 hPa for pressure, and 35% for relative humidity must be flagged; and (3) Internal coherence test to verify that values fulfil the condition maximum > mean > minimum. During this process, no values were corrected or deleted.

After the basic quality control was applied, the daily and monthly mean average series were constructed. It is worth mentioning that the no filling gaps method was used, as the raw data have few missing values (less than 7%). Towards identifying irregularities in the observed climate dataset and their subsequent adjustment, only the monthly series were subjected to homogeneity testing. A homogeneous climate series can be defined as a series that is only influenced by the variation in climate. As Brázdil et al. [16] pointed out, all observational rescued data require quality control to reflect the real climate variations rather than the influence of non-climatic factors, and this is of relevance in the case for historical observations that have not been taken using modern standards and techniques. When weather stations record long-term climate data series, inhomogeneous records or non-climatic factors may occur in the series because of the method used for data collection, conditions around the observation site, reliability of the measurement, site relocation, etc. [17]. However, a daily series tends to have high variability that reduces the effectiveness of detecting shifts in its mean over time, and therefore, homogenization procedures tend to be more useful in monthly series. It should be noted that, in this way, daily climate inhomogeneity became smoothed using the monthly inhomogeneity values [18].

The homogeneity test for the monthly mean series was conducted using XLSTAT statistical software (2023.2.0). The tool is a data analysis and statistical application available for Microsoft Excel and utilizes statistical tests to detect the presence of inhomogeneities in the data. Four tests were applied: The Pettitt's test, Alexandersson's SNHT test, Buishand's test (BRT), and von Neumann's ratio test (VNRT). Under the null hypothesis (Ho), the annual values of the testing variables are independent and identically distributed, and the series are considered homogeneous. On the other hand, under the alternative hypothesis (Ha), the SNHT, BRT, and Pettitt tests assume that the series have a break in the mean and are considered as inhomogeneous [19]. Some differences must be noted between the tests. The SNHT, BRT, and Pettitt tests are capable of detecting the year where a break occurs; meanwhile, the VNRT assumes the same null hypothesis as the previous ones, but for the alternate hypothesis, it assumes that the series is not randomly distributed and assesses the randomness of the series but does not give the year of the break. In all cases, if the test statistic exceeds the critical value at a certain confidence level, the null hypothesis will be rejected at that confidence level. For all four tests, if the test statistic exceeds the critical value at a certain confidence level, the null hypothesis will be rejected at that confidence level. In this study, the result of each method was evaluated at a 5% significance level. The results derived from the applied homogeneity tests were interpreted by following the approach suggested by Wijngaard et al. [20]. Based on this approach, the series can be classified into three classes: 'useful' if one or zero tests reject the null hypothesis at the 5% significance level; 'doubtful' when two tests reject the null hypothesis at the 5% significance level; and 'suspect' if three or four tests reject the null hypothesis at the 5% significance level.

To further assess the performance of Puerto Madryn's measurements, the monthly means homogeneous series were compared with the Twentieth Century Reanalysis (20CR) product in annual and seasonal time steps (summer (DJF), autumn (MAM), spring (SON), and winter (JJA)). The 20CR latest version was developed by the University of Colorado Boulder's Cooperative Institute for Research in Environmental Sciences (CIRES) together with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Energy (DOE). The 20CR version 3 (20CR v3) assimilates a larger set of observations with high resolution and extends the reanalysis period to 1836–2015 with an experimental extension spanning 1806–1835 [21]. To this aim, the monthly mean series of the variables under analysis were retrieved within one degree around Puerto Madryn for the period 1902–2015.

Additionally, the Spearman correlations between the homogenized dataset and 20CR v3 values were conducted. A trend analysis of the variability in all the annual variables was also evaluated by means of the Mann–Kendall (MK) test using the homogenous monthly mean series data. The MK test detects the presence of a monotonic tendency in a chronological series of a variable. It is a nonparametric method; thus, no assumptions about the underlying distribution of the data are made, and its rank-based measure is not influenced by extreme values. This method mainly gives three types of information: (a) The Kendall Tau or Kendall rank correlation coefficient measures the monotony of the slope, varies between -1 and 1, and is positive when the trend increases and negative when the trend decreases; (b) the Sen slope, which estimates the overall slope of the time series, corresponds to the median of all the slopes calculated between each pair of points in the series; and (c) the significance, which represents the threshold for which the hypothesis that there is no trend is accepted, is statistically significant when the p-value is less than 0.05. Finally, an alternative method to evaluate the observations was applied by means of the Spearman correlations between the RH and the other variables.

3. Results

Figures 3 and 4 show a series of panels with the results of the homogenization tests for the monthly average series of pressure; maximum, minimum, and average temperatures; as well as relative humidity. Please note that breakpoints are defined as values in the data series with a too high or too low value compared to the previous and/or following records and that are believed to be the result of inhomogeneity in the data series and not from the original climate signal in Puerto Madryn. Table 1 summarizes the results for the three tests shown in the figures, including the results of the VNRT. For the qualitative interpretation of the four tests, the results were evaluated qualitatively using the approach of Wijngaard et al. [20]. The test shows that, under this approach, the temperature series can be considered as homogeneous, while pressure and relative humidity have shifts in March 1903 and September 1908, respectively. To proceed further with the analysis, the series were homogenized and retested with the same four tests previously applied (Figure 5).

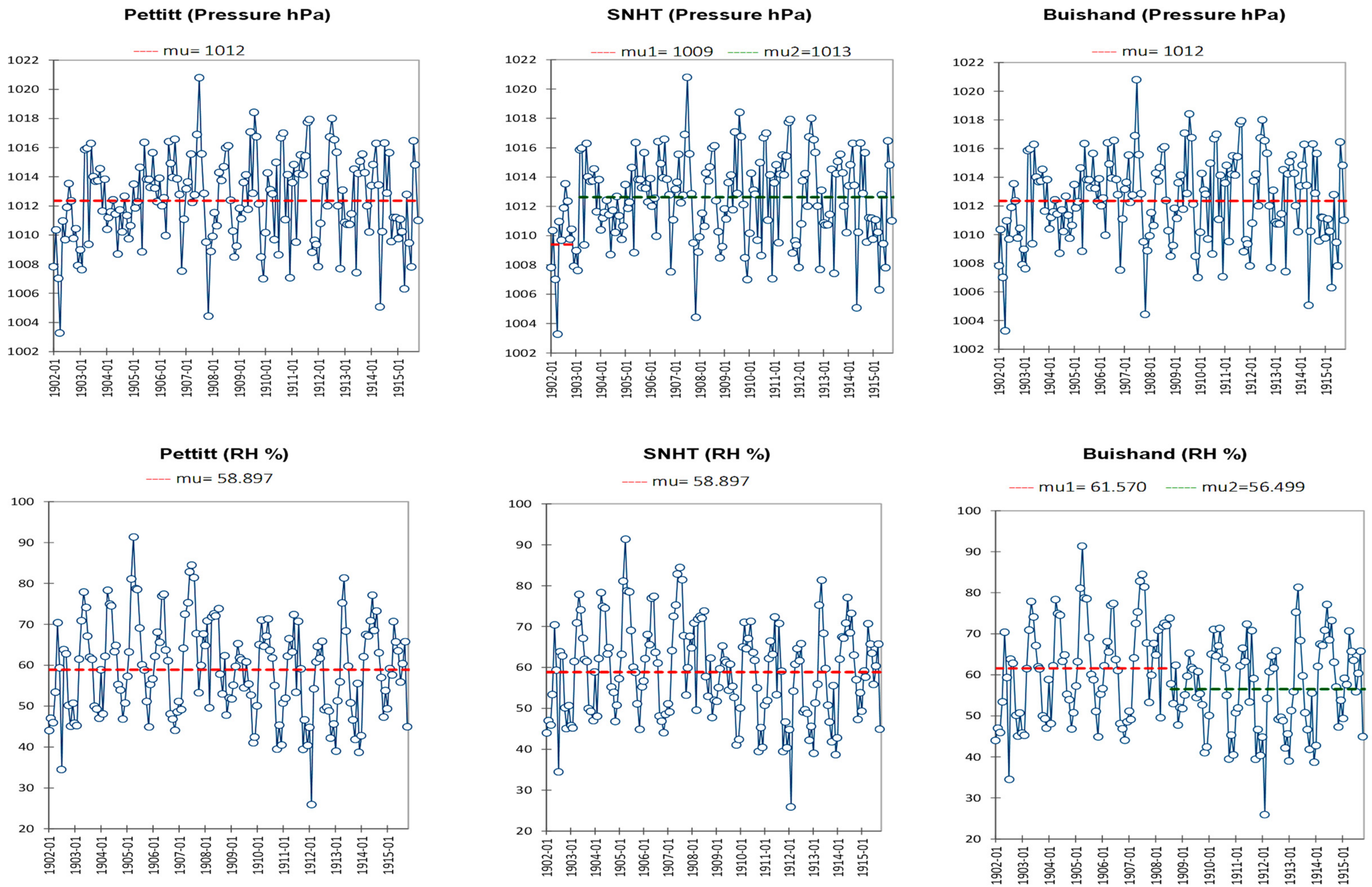


Figure 3. Break year for monthly mean pressure (**upper panel**) and relative humidity (**lower panel**) in Puerto Madryn, 1902–1915. The values of mu1 and mu2 represent the mean variable value before and after the change point.

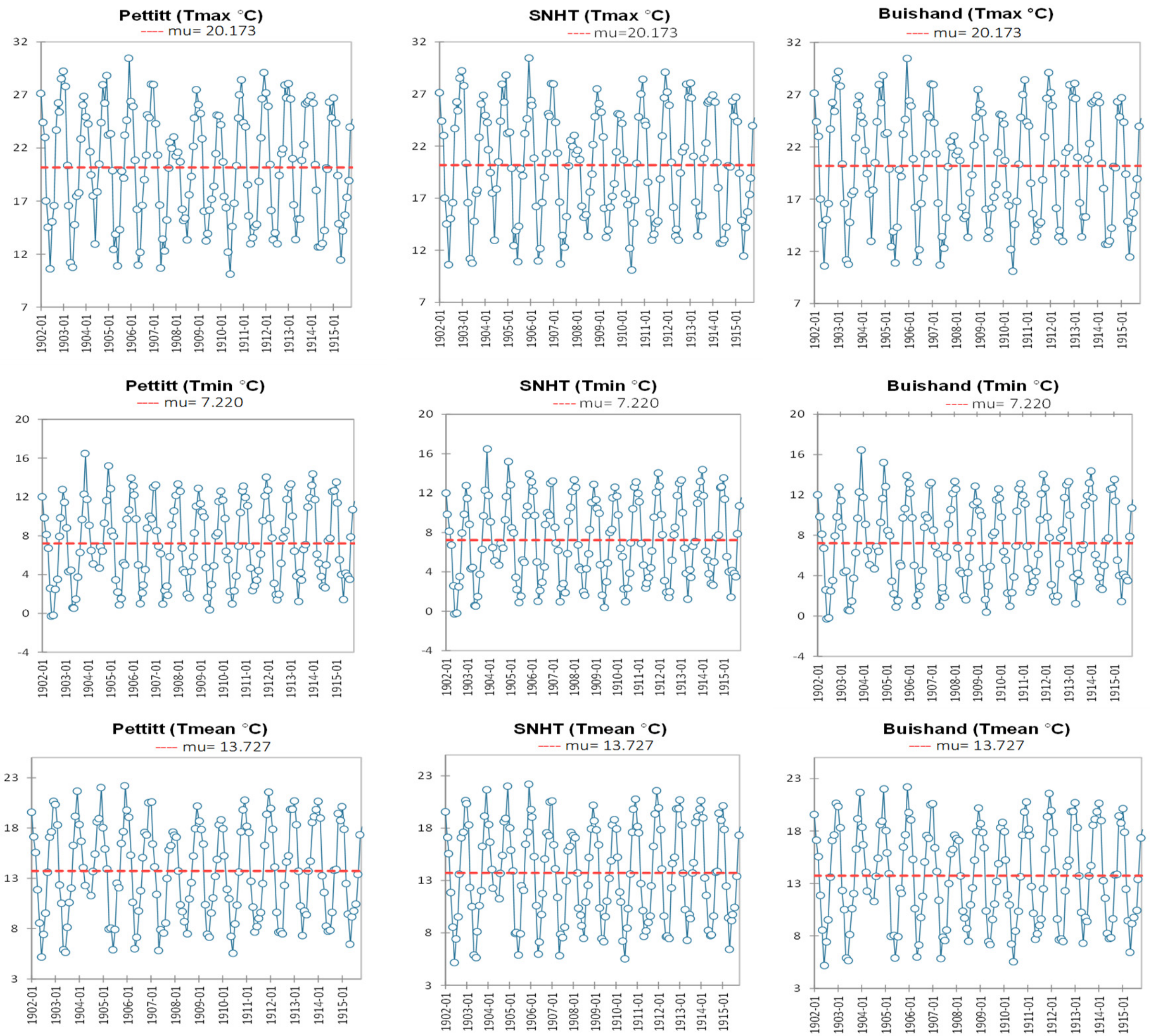


Figure 4. Same as previous but for monthly maximum (**upper panel**), minimum (**middle panel**), and mean temperature (**lower panel**) values in Puerto Madryn, 1902–1915.

Table 1. The *p*-values obtained from the homogeneity tests for the variables used for Puerto Madryn. Bold numbers represent $p < 0.05$, indicating inhomogeneity in the corresponding time series at a 5% significance level. Class corresponds to the Wijngaard's classification criteria.

Variable	Pettitt	SNHT	Buishand	Von Neumann	Class	Breakpoint Date: Month/Year
Pressure (hPa)	0.270	0.003	0.150	<0.0001	doubtful	3/1903
RH (%)	0.150	0.118	0.028	<0.0001	doubtful	9/1908
Tmean (°C)	0.078	0.952	0.965	<0.0001	useful	--
Tmax (°C)	0.577	0.901	0.719	<0.0001	useful	--
Tmin (°C)	0.52	0.593	0.722	<0.0001	useful	--

An alternative way to evaluate the behavior of observational data is, when available, to integrate them with larger series from different sources and to analyze possible differences. According to Kalnay et al. [22], a reanalysis can provide a complete and coherent overview of atmospheric fields by combining historical observations with forecasts from numerical weather prediction models. Figures 6 and 7 show the monthly series from the observational homogenized data integrated with the 20CR v3 values and the differences between both datasets. It should be noted that, although reanalysis values are available for earlier years, for simplicity and to improve the resolution of these figures, only the period 1900–1920 was considered. As the figures show, the minimum and maximum temperature values represent quite a good upper and lower bound for the temperature mean values, both observational and reanalysis data (Figure 6a). Overall, the two monthly mean datasets are in very good agreement, and only in the winter of 1904, a difference of more than 9 °C can be detected between both datasets (Figure 7a); however, it should be noted that this "difference" is probably related to the lack of some minimum temperature values in June 1904.

On the other hand, the pressure series (Figure 6b) show two clear differences between the values: The observational data are higher at the beginning of the period, especially between 1902 and 1903, while between 1913 and 1915, on the contrary, the 20CR v3 values are the highest. This result is also evident in Figure 7b with a clear decreasing trend along the period.

Regarding humidity (Figure 6c), along the whole period, the observational data are higher than the reanalysis values, and the differences seem to show a quasi-seasonal pattern with the observational values tending to be higher in the summer and the reanalysis data tending to be higher in the winter (Figure 7c). Regarding the absolute values, the largest differences correspond to the years 1902 and 1912. In all cases, the annual cycle is recognizable for all the variables, and the behavior fits well with the reanalysis. Seasonally (Figure 8), the larger differences correspond to MAM and DJF for the temperature and pressure values, respectively. Concerning relative humidity, all seasons show observational data above the 20CR v3 values, although in MAM, the differences are higher. Agreements between the two datasets were also examined with the Spearman correlation. Table 2 displays the coefficients, confirming that the higher correlations are detected between the monthly mean temperature (0.94), and as expected, the lower coefficients are found for the pressure and relative humidity values (0.61 and 0.65).

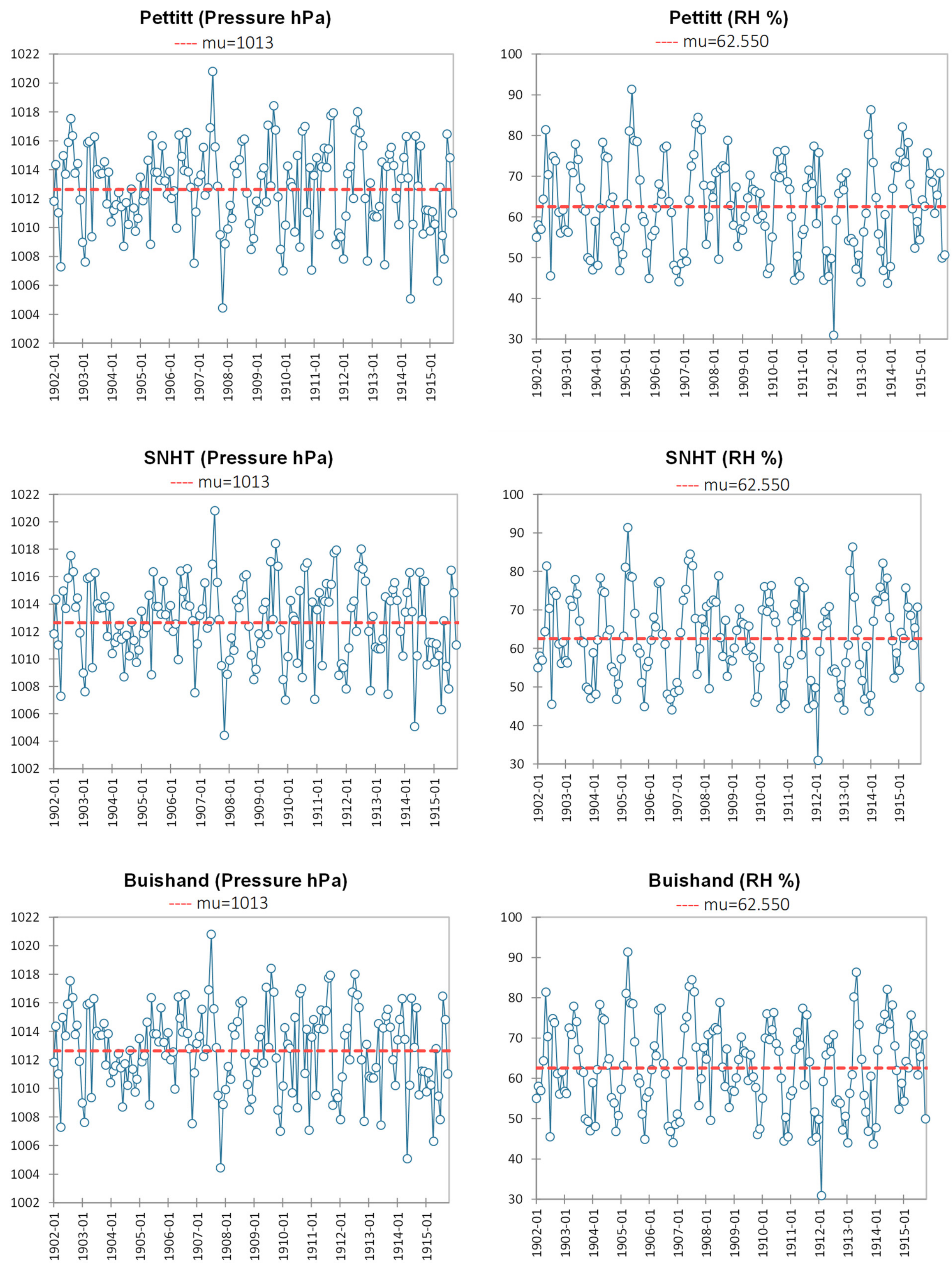


Figure 5. Homogenized monthly data series of pressure (**left side**) and relative humidity (**right side**).

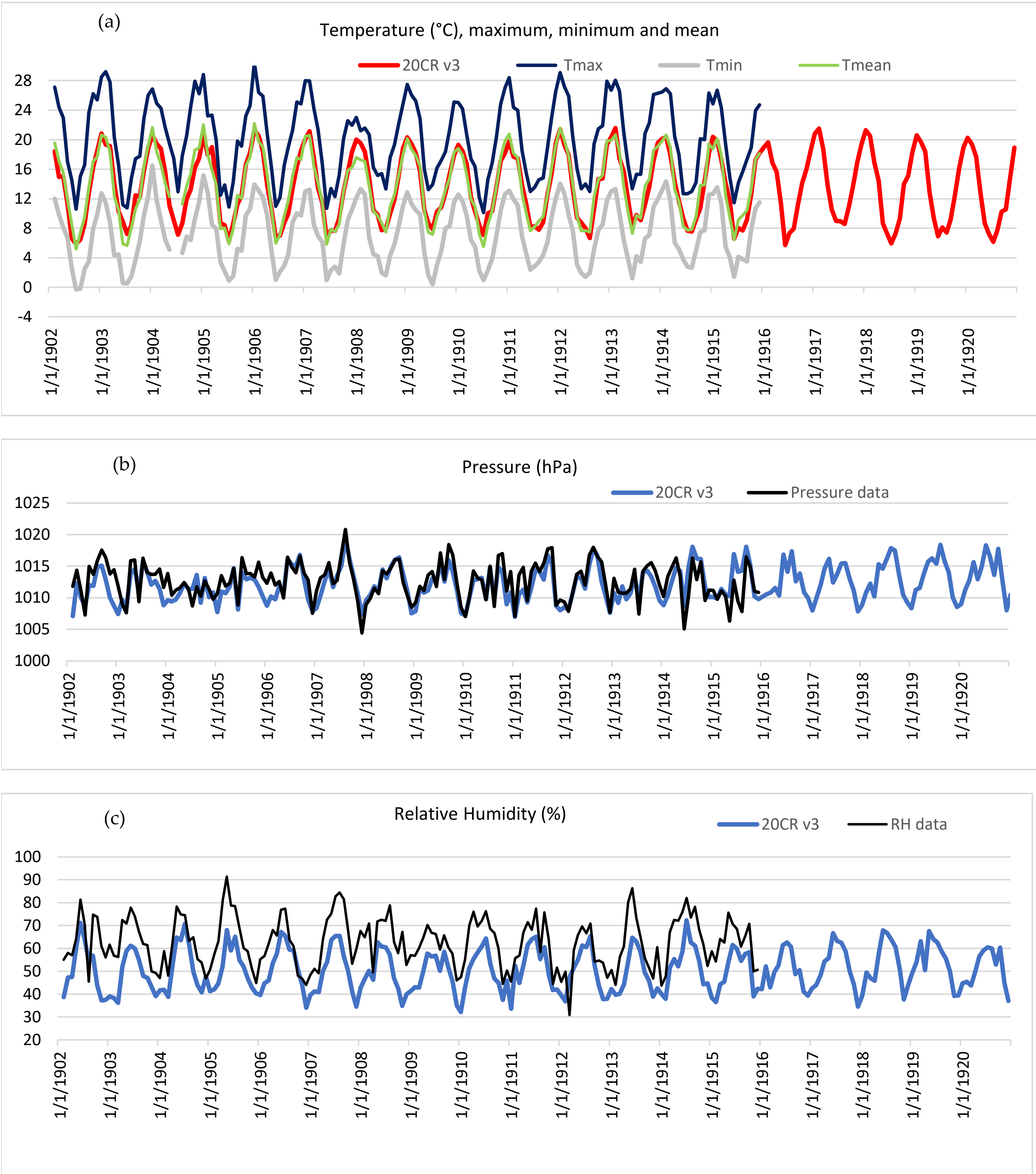
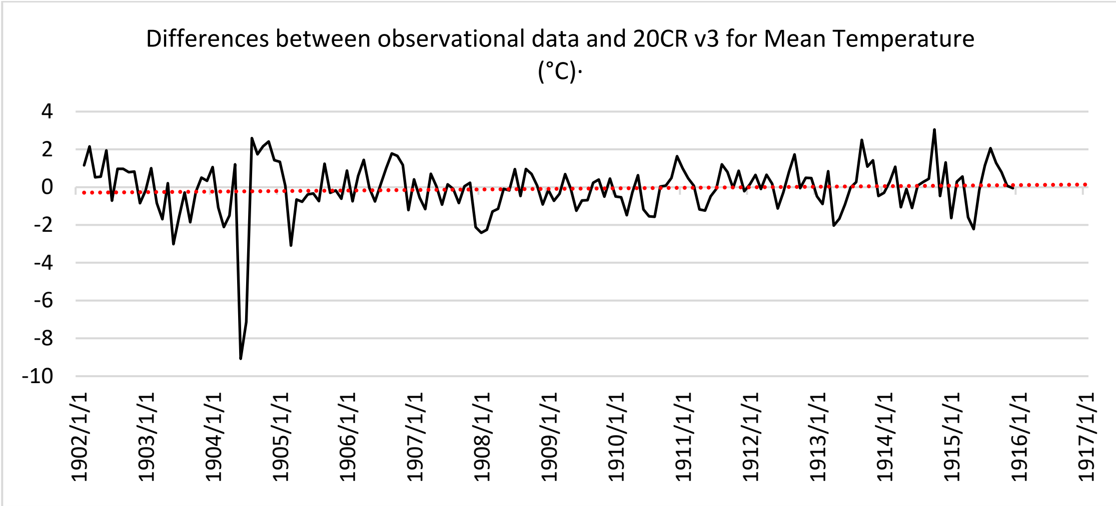
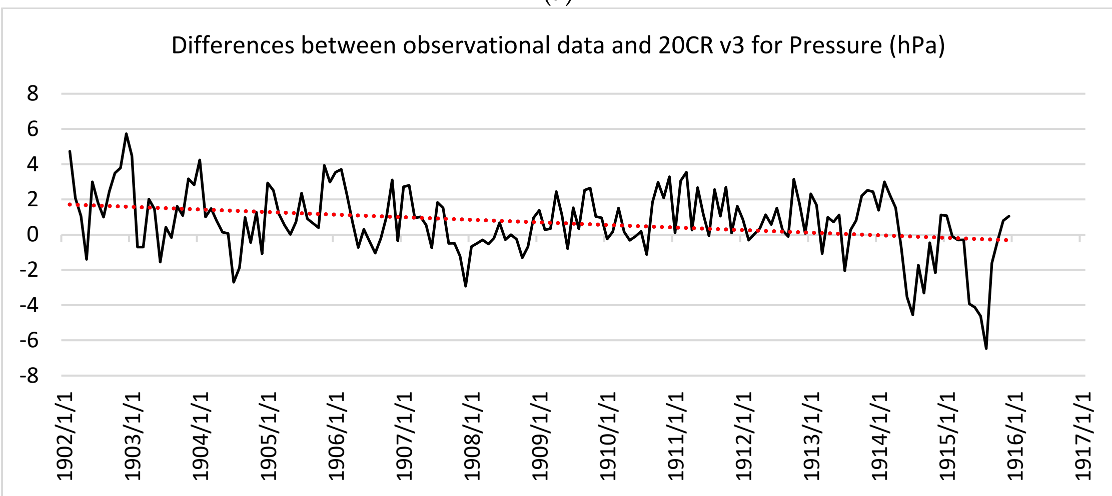


Figure 6. Homogenized observational data integrated with the 20CR v3 series for (**a**) mean, maximum, and minimum temperatures, (**b**) pressure, and (**c**) relative humidity.



(**a**)



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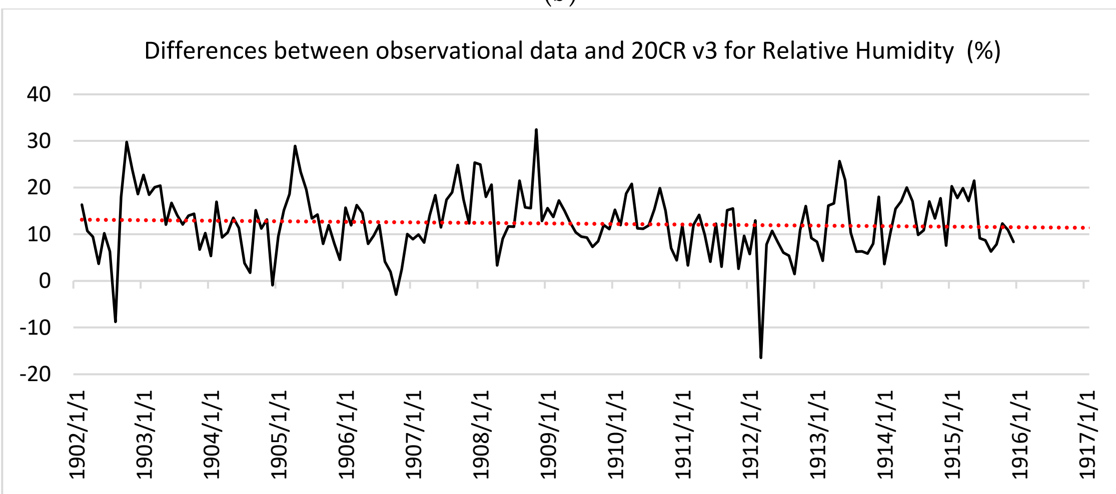
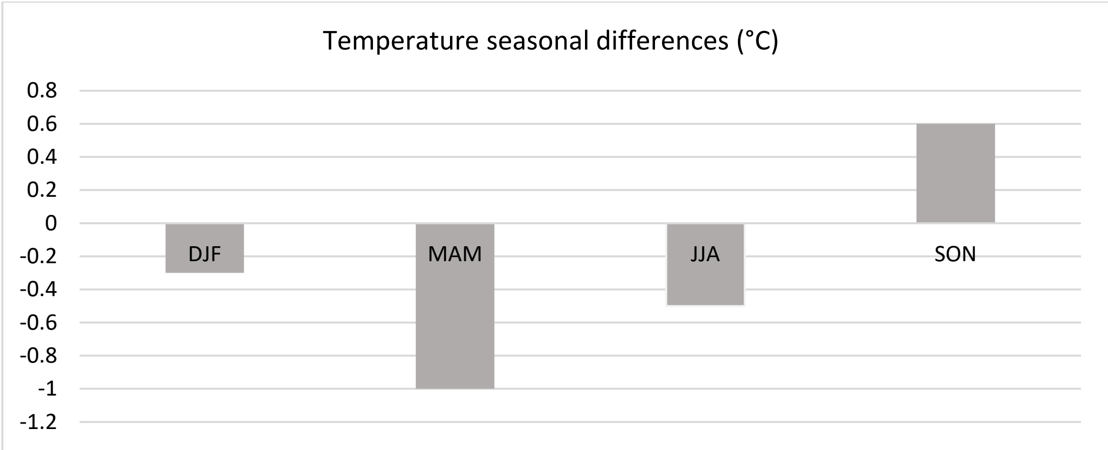


(**c**)

Figure 7. Differences between homogenized observational data and 20CR v3 reanalysis values for (**a**) mean temperature, (**b**) relative humidity, and (**c**) pressure.



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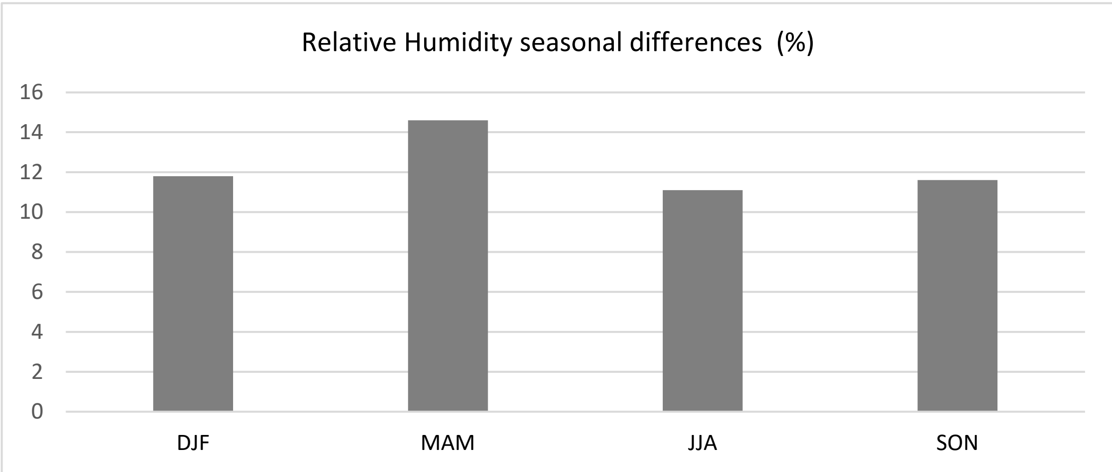

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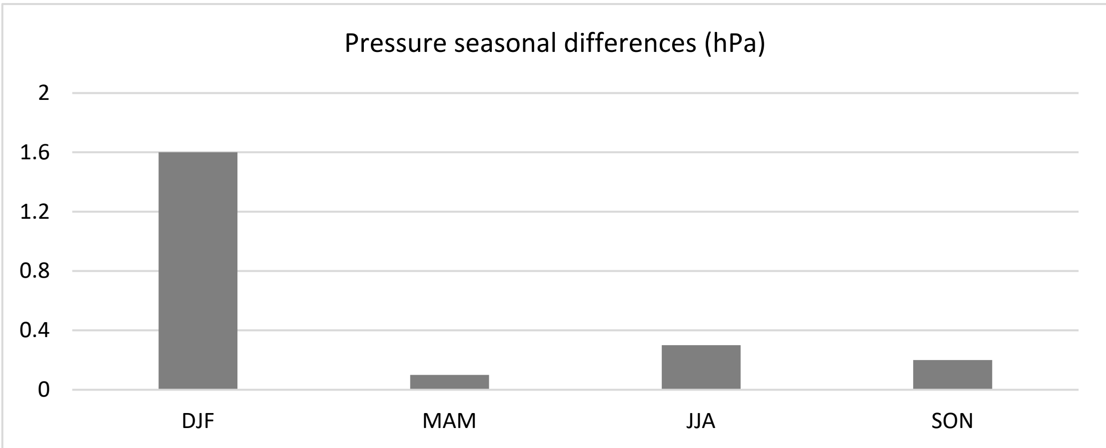


(**c**)

Figure 8. Seasonal differences between homogenized data and 20CR v3 for (**a**) temperature, (**b**) relative humidity, and (**c**) pressure.

Table 2. Coefficients of Spearman correlation between homogenized observational data and 20CR v3.

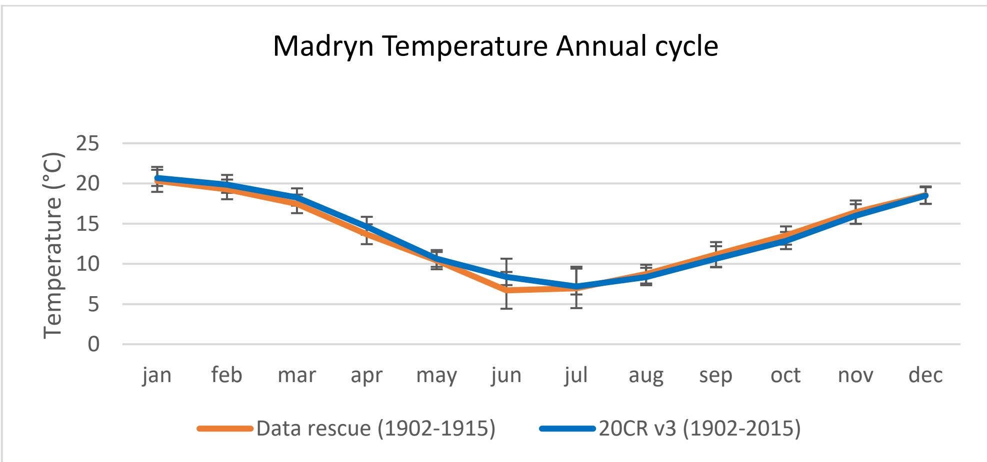
Variables	Spearman Correlation Coefficient (Significance Level (α = 0.05))
RH data vs. 20CRv3	0.65
Tmean data vs. 20CRv3	0.94
Pressure data vs. 20CRv3	0.61

In order to better assess the performance of the measurements, the changes in the annual cycles of all variables were tested (Figure 9). Note that, in this case, the most recent climate records were included in the 20CR v3 dataset (1902–2015). The results show that the monthly standard deviations are statistically significant in the monthly mean relative humidity values in almost all the months.

Although the monthly time series corresponds to a short period of data, the trend of each climate variable using the homogenized data series was computed in annual time-step by means of the Mann–Kendall (MK) test with XLSTAT. The results, summarized in Table 3, show that no trend can be detected in the homogenized series. However, it should be noted that the MK results are more statistically significant when testing the longer time series.

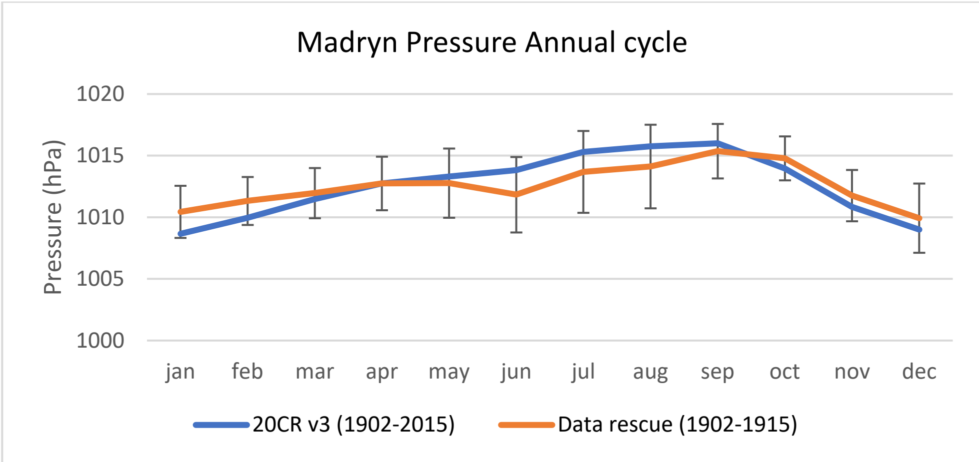
Table 3. Mann–Kendall test indicator results for all the variables studied in Puerto Madryn.

Variable	S/Tau	*p*-Value	Mann–Kendall Test Trend	Sen's Slope
Tmax	−393/−0.028	0.587	No trend	−0.00016
Tmin	554/0.444	0.444	No trend	0.00017
Tmean	14/0.001	0.986	No trend	0.00000
Pressure	−613/−0.044	0.397	No trend	−0.00014
RH	−307/−0.022	0.672	No trend	−0.00028



(**a**)

Figure 9. *Cont.*



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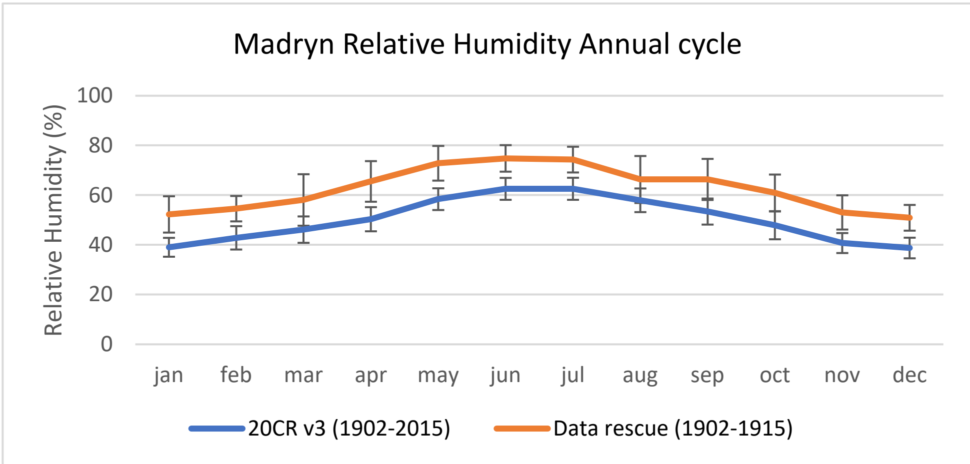

(**c**)

Figure 9. Mean annual cycles of (**a**) temperature, (**b**) pressure, and (**c**) relative humidity at Puerto Madryn for the data rescued period 1902–1915 and 20CR v3 data from 1902–2015. Error bars show the standard deviation of the sample mean.

To validate Madryn's measurements, correlations between RH and the other variables were performed. Figure 10 shows the results. As expected, a negative higher Spearman correlation is observed in (a) to (c), meaning that humidity is inversely correlated with temperature. There is no considerable difference between the maximum and minimum temperatures with coefficients of approximately −0.5 and −0.6. No dependence of pressure on the humidity measurements can be observed, as the Spearman coefficient is almost null. Similar results were found for temperatures in the analysis by Pliemon et al. [23] who evaluated the correlation analysis of Morin's humidity measurements with various meteorological variables between May 1701 and June 1711. The results show that a negative correlation is also observed between temperature and humidity, although with lower coefficients (r approximately −0.2).

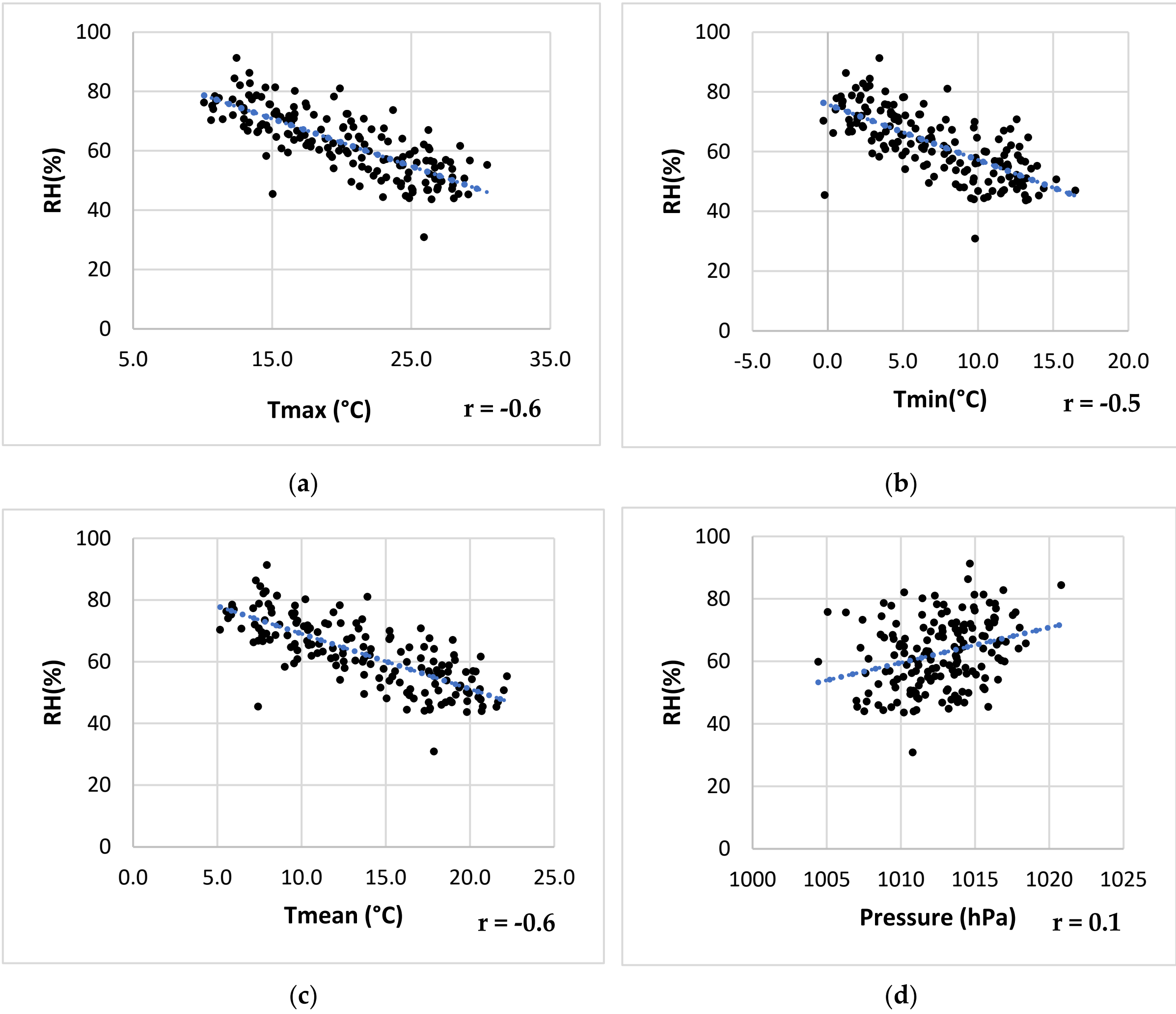

Figure 10. Correlation between relative humidity and (**a**) maximum temperature, (**b**) minimum temperature, (**c**) mean temperature, and (**d**) pressure.

4. Summary and Conclusions

This manuscript presents, for the first time, rescue and quality control daily meteorological observations performed at Puerto Madryn, Patagonia Argentina. The data cover a period spanning from 1902 to 1915 and are composed of daily measurements of maximum, minimum, and mean temperatures; relative humidity; and pressure. The daily observations and the metadata have been recovered from the original printed registers of the Annals of the Oficina Meteorológica Nacional. The digitization process was performed with key entry from the photographed documentary. The daily data have been quality-controlled using the tolerance test, temporal consistency, and internal coherence. It should be noted that no data were deleted from the original measurements, and the no filling gaps procedure was applied. The monthly mean series were constructed from the daily raw data and were subjected to a homogenization process. The results reveal discontinuities in relative humidity and pressure in September 1908 and March 1903, respectively. Unfortunately, no metadata are available to attribute these shifts to changes in instrumentation or location. As an alternative way to study Puerto Madryn's measurements, the monthly mean homogeneous series were compared with the 20CR v3 values. The results show that the series of maximum and minimum temperatures represent an excellent upper and lower limit for the mean temperature values of the 20CR v3 and even of the measured data. Although the series extend over a short period of time, this could represent a valuable contribution to the reanalysis background related to the South Cone climate.

The pressure and humidity values also match very well with reanalysis, although the agreement is slightly lower than that for the temperature values. Further evidence for the plausibility of the measurements is given by the Spearman correlation coefficients between both datasets with a correlation coefficient of approximately 0.94 for the temperature comparison and a value of approximately 0.6 for pressure and relative humidity. The differences between the two datasets in annual and seasonal time steps were also examined, and the largest temperature discrepancies in the annual series are found in the winter of 1904 with a difference of 9 °C in the absolute value. However, it should be noted that this difference seems to be related to the missing minimum temperature values in June 1904. As for pressure, differences are detected at the beginning and at the end of the period with the highest values at the beginning corresponding to the measurements while at the end corresponding to the reanalysis. Seasonally, the largest differences correspond to MAM and DJF for the temperature and pressure values, respectively. For humidity, over the whole period, the observational data are higher than the reanalysis values, and the differences seem to show a quasi-seasonal pattern with the observational values tending to be higher in the summer and the reanalysis data tending to be higher in the winter. Regarding the absolute values, the largest differences occur in 1902 and 1912. In all cases, the annual cycle is recognizable for all measurements. The Mann–Kendall procedure shows no evident trends for any of the variables. A larger series of the variables could be needed to reconfirm these results. The relative humidity dependence on the other variables was assessed by means of the Spearman correlation, and the results show that relative humidity is, as expected, inversely correlated with temperature, and the correlation with pressure is almost null.

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