Recovery of Meteorological Data for the Observatory of A Guarda, Spain

Juan A. Añel1,2*, Marcos Blanco-Durán2, Luis Gimeno2, Laura de la Torre2

1 Smith School of Enterprise and the Environment, University of Oxford, Oxford, United Kingdom, 2 EPhysLab, Facultade de Ciencias, Universidad de Vigo, Ourense, Galicia, Spain

Abstract

We herein describe the recovery of a series of data on temperature, humidity, precipitation, evaporation, wind, and local weather conditions from documentary sources obtained from the Jesuit observatory of A Guarda (Galicia, Spain) for the period 1881–1896. The data were digitized and made available in accessible electronic formats. Comparisons were made with present-day meteorological data obtained from two nearby stations. We further believe that the discovery of some new complementary documentary sources made during the present research could be a basis for future data recovery efforts. Among these new results, early ozone data from the period are of outstanding importance to meteorologists.

Introduction

The recovery of instrumental meteorological records from printed manuscripts are of great importance for paleo-climatological studies [1]. The International Environmental Data Rescue Organization (IEDRO) states that the main benefits of data recovery lie in the study of climate change, as well as for disease prevention, flood forecasting, the design of safer infrastructure, the prevention of famine and for the general understanding of climate in historical terms. According to the World Meteorological Organization (WMO), such recovery includes the storage of the recovered data in the form of digital media that are easy to read and access [2]. The WMO recently introduced the Mediterranean climate data rescue (MEDARE) initiative, with the aim of developing and improving data recovery activities for the Greater Mediterranean Region [3]. They have been launched in the last years the “Data Rescue at Home” (http://www.data-rescue-at-home.org/) project as an “attempt to digitize historical weather data from all over the globe and the “International Atmospheric Circulation Reconstructions over the Earth (ACRE)” initiative [4]. Instrumental data recovery is of great importance for years before 1940’s because of the lack of good meteorological records, and some efforts have already been made in the North Atlantic region, for example, to reconstruct time series pertaining to the North Atlantic Oscillation (NAO) [5], which is the dominant mode of variability of winter climate in the North Atlantic region [6,7]. Particularly important in studies of this type are the Spanish historical archives, which are recognized to be a vast store of meteorological information that deserve special attention and could be used as a basis for data recovery efforts [8,9].

The Society of Jesus (the “Jesuits”) has maintained an interest in the natural sciences since its foundation in 1540. The results of such a scientific tradition (documentary sources, observatories, reports, etc.) are of broad interest in several disciplines, with meteorological and climatological studies being among the most prominent. The Jesuits were a highly educated community and the reliability of their data is likely to be high [10,11].

Combining these two issues of supply and demand, we herein present the results of a study of recovery and digitization of documentary sources of meteorological data obtained from the Jesuit observatory of A Guarda, Spain. The study was undertaken with the aim of contributing to global efforts in data rescue and for the study of regional climatological patterns for the northwestern Iberian Peninsula, a region strongly affected by the NAO [12,13]. The national weather services of Spain have previously recovered and digitized large amounts of meteorological data [14]. However, the location and period of measurement of the data here presented herein, together with the fact that the data were only ever sporadically transmitted to the national central observatory of Spain [15], make their systematic recovery particularly valuable.

The remainder of the paper is organized as follows: we first present a materials and methods section, containing information about the observatory, a description of the data series used for comparative purposes, and a description of the existing documentary sources, summarizing their information in a set of tables. Secondly, we present the results of the digitization of the data, some figures in which the historical data are compared with data from the present day, and we also describe a new documentary source discovered during the present study. In the conclusions, we discuss the outcomes of the project and suggest future avenues of enquiry.
Materials and Methods

The Observatory of A Guarda and Metadata

The observatory at the centre of our study was located in A Pasaxe, Santa Isabel de Camposancos, A Guarda, Pontevedra (Spain). According to the bibliographic data [16], it was situated at latitude 41°52′ and longitude 5°7′ West of Madrid (Spain) (8°49′ West of the Greenwich meridian). It was part of the “Apóstol from the Atlantic Ocean [11,15].

The observatory was at sea level (though in parts of the documentation is indicated to be in a height of eight meters) in a building with a hexagonal floor in the gardens of the main college. Its height was 2.5 m from floor to ceiling, with a total roof height of 0.8 m. Wooden planks were set in the easter, southern and western walls like blinds, to avoid the direct impact of solar radiation on the instruments. All the instruments were located at an elevation of 1.5 m above the floor and the altitude of the barometer relative to mean sea level was 8 meters. The instrumentation in the observatory included:

- Wallerardin maximum thermometer
- Rutherford minimum thermometer
- Bellani thermograph
- psychrometer
- Tonneclot rain gauge
- Eon Fils barometer
- evaporimeter
- minimum thermometer exposed to solar radiation
- maximum thermometer exposed to solar radiation
- weather vane

The observatory was operational by the end of November of 1890. From 1890 onwards, daily reports of the observations were sent to the Instituto Central Meteorolóxico de Madrid (the principal meteorological institute of Spain) and the data were published in annual bulletins. Furthermore, between 1891 and 1897 the observatory of A Guarda published a number of bulletins entitled “Colegio de La Guardia. Boletines meteorológicos” (A Guarda College. Meteorological bulletins). At some point between 1903 and 1911, the observatory was moved to a tower built on the southern side of the college. We found no reference pertaining to the location of the observatory between 1911 and 1917. The observatory stopped working by 1917.

Monte Aloia and Vigo-Peinador

In order to compare the data obtained from A Guarda with data from the present day, we used data from the automatic weather station “Monte Aloia” and the meteorological observatory “Peinador”. Monte Aloia is the closer weather station to A Guarda but it lies in a much higher altitude and its data series is short which makes harder the comparison of results based on pressure. Peinador is the closer observatory with a 30 years climatological series.

The Monte Aloia automatic weather station is operated and maintained by the Regional Government of Galicia. We chose this station for three main reasons. Firstly, it lies close to the former observatory of A Guarda, at approximately 27 km from its original location; secondly, the data series for this station for the period 2001–2010 show a good temporal homogeneity. Moreover, and thirdly, both the data and metadata are publicly available at http://www.meteogalicia.es. The station is located at 42.08° N and 8.68° W, and it lies at an elevation of 404 m above sea level.

The observatory located in Peinador (known as Vigo-Peinador) is operated by the Spanish meteorological agency (AEMET). The observatory is located at 42.24° N and 8.62° W, and it lies at an elevation of 261 m above sea level. The distance to the observatory of A Guarda is approximately 45 km. The data and metadata are available in the web page of AEMET (http://www.aemet.es) and at http://eca.knmi.nl provided by the ECA&D project [17].

Materials

This study is based on the publications and observations made at the observatory by Father Baltasar Merino. Copies of his four notebooks (in Spanish), are kept at the library of the Observatori de l’Ebre, an observatory situated in Roquetes (Spain), which was also originally founded by the Jesuits. Figure 1 shows the period covered by the data recovered for the present study.

We now describe the documentary sources by applying the structure recently suggested by Bronnimann et al. [1].

Notebook I. Published in 1891, this is the first of the books on the meteorological characterization of the site written by Father Baltasar Merino. Its original title was “Resumen de las Observaciones Meteorológicas efectuadas en el Colegio de La Guardia, de la Compañía de Jesús, durante el decenio de 1881 a 1890” (Summary of the meteorological observations for the A

Figure 1. Period covered by the data recovered.
doi:10.1371/journal.pone.0039281.g001
RESUMEN
DE LAS
OBSERVACIONES METEOROLÓGICAS
EFECTUADAS EN EL
COLEGIO DE LA GUARDIA, DE LA COMPAÑÍA DE JESÚS,
DURANTE EL DESENIO DE 1881 Á 1890,
E INDICACIONES SOBRE EL CLIMA DE AQUELLA LOCALIDAD,
POR EL
P. DON BALTASAR MERINO

(Publicado por el Observatorio de Madrid.)

MADRID
IMPRENTA DE RAFAEL MARCO Y VIÑAS
Calle de San Cipriano 1,
1891

Figure 2. First page of the Notebook I [16].
doi:10.1371/journal.pone.0039281.g002
Guarda College, of the Society of Jesus, for the decade 1881 to 1890 [16]. This notebook contains descriptions of the observatory, its location, the materials used to build it, as well as the instrumentation and the metadata for the measurement procedures.

Figures 2, 3 and 4 show the cover of the notebook and some examples of data included therein. The characteristics of the data contained in the notebook are given in Table 1. The data include readings of pressure and temperature (mean, minimum and maximum), as well as oscillations (diurnal and maximum), mean relative humidity, vapor pressure, precipitation (number of days with rainfall and depth of rainfall), mean evaporation, general observations of weather, as well as wind speed and direction. All the data are shown as monthly, annual and five-year values. The data series are splitted into two different series, namely “A”, where the different variables are displayed jointly in the same table in annual and seasonal periods, and “B”, with a different table for each variable shown (Figure 3). The last part of the notebook contains comparative graphs of the different variables studied. An example is provided in Figure 4.

**Notebook II.** Notebook II was published in 1893 under its original title “Estudio sobre las Borrascas en la costa occidental de Galicia” (Study of extratropical cyclones for the western coast of Galicia) [18]. It should be noted that the criterion used in this notebook to denote an extratropical cyclone is not the same as the WMO criterion, as will be explained later. In this notebook Father Merino proposed, at the end of the 19th century, the constitution of a European meteorological service that would focus on the Atlantic region. Table 1 shows the characteristics of the data contained in this notebook, which cover the period 1881–91.

The main focus of Notebook II is the study of low pressures and of meteorological phenomena that affect sailing. It therefore contains a complete description of the aneroid barometer and its applications. It starts with an analysis of the dangers of low-pressure areas to sailors and contains a complete study of the their characteristics when arriving at the west coast of Galicia. A methodology for forecasting this phenomenon is also proposed. The data contained in the notebook are values of pressure and wind speed and direction for some days, measured twice a day (morning and evening), before, during and after the occurrence of different low pressure systems. Figure 5 shows an example of a typical entry in this book.

**Notebook III.** Published in 1894, this notebook was entitled “Observatorio Meteorológico del Colegio de la Compañía de Jesús en La Guardia. Cuaderno Tercero” (Meteorological observatory of the College of the Society of Jesus in La Guardia. Third notebook) [19]. It contains a study of meteoric water and its impact on temperature at A Guarda. It is followed by a complete description of the sources of meteoric water and the process of evaporation in the Atlantic coast of Galicia, with information about its mean temperature, surface and mean daily evaporation. Father Merino explained the process of evaporation for the Atlantic Ocean, focusing on the warmest part of the northern Atlantic Ocean, and estimating an area of $17 \times 10^6 \text{km}^2$ and a sea surface temperature of 25°C. He calculated the rate of evaporation per square metre by taking into account the area under consideration and multiplying it by the mean daily evaporation, and then explained the process from evaporation to precipitation.

The characteristics of the data contained in the notebook are shown in Table 1. The recorded data cover the period 1892–3,
Figure 4. Example of a graph of precipitation and evaporation from Notebook I [16].
doi:10.1371/journal.pone.0039281.g004
and are shown by splitting each month into three periods of ten days (termed “décadas” in the notebook) and comprise:
- mean, maximum and minimum values of temperature
- monthly mean values of temperature
- number of cloudy days and quantification of cloud cover (cloud-free, cloudy, obscured)
- dominant winds
- days with precipitation and depth of rainfall (in mm, L and L/m²)

Figure 6 shows a page of this data as recorded in the notebook. The notebook also contains two tables: the first shows the monthly amount of water recorded in the rain gauge, including the depth in mm, the volume in litres and the corresponding number of litres per square metre (see Figure 7); the second shows an estimate of the total quantity of water (in litres) precipitated in the valley in which the observatory was located (with an estimated total surface area of 1×10⁶ m² and the corresponding values of calories emitted) (see Figure 8). A procedure for the analysis of dissolved chlorine and ammonia in the rain measured for 1893 and 1894 is also explained.

**Notebook IV.** Published in 1897, the fourth notebook is entitled: “Observatorio Meteorológico del Colegio de la Compañía de Jesús en La Guardia. Cuaderno Cuarto” [Meteorological observatory of the College of the Society of Jesus in La Guardia. Fourth notebook] [20]. It includes meteorological observations for the period 1891–6. The characteristics of this notebook as a source of data are shown in Table 1 and an example of the information that it contains can be seen in Figure 9.

The first part of this notebook contains a study of the relationship between the vegetation and temperature in the drainage basin of the Miño river. Monthly values of temperature are given for the period 1891–6, and the months are split into periods of ten days called “décadas”. For these periods the variables recorded and averaged are the maximum temperature in the sun, the maximum temperature in the shade, and their difference, the minimum temperature in the shade, the minimum reflected temperature and the difference between them, and the mean, maximum and minimum soil temperature at a depth of

---

| Formal | Source format | Photocopy |
|--------|---------------|-----------|
| Information type | numeric, text, graphical |
| Information format | tables, text |
| Notebook I | Typing | printed |
| Legibility | clear |
| Informational | Data coverage | Observatory of A Guarda, 1881–1890 |
| Quality | good |
| Redundancy | reports from the local newspaper “La Integridad” |

---

**Table 1. Characteristics of the data contained in the notebooks.**

| Notebook I | Typing | printed |
| Information format | tables, text |
| Legibility | clear |
| Informational | Data coverage | Observatory of A Guarda, 1881–1890 |
| Quality | good |
| Redundancy | reports from the local newspaper “La Integridad” |

---

| Notebook II | Typing | printed |
| Information format | tables, graphs, text |
| Legibility | clear |
| Informational | Data coverage | Observatory of A Guarda, 1881–1891 |
| Quality | good |
| Redundancy | reports from the local newspaper “La Integridad” |

---

| Notebook III | Typing | printed |
| Information format | tables, text |
| Legibility | clear |
| Informational | Data coverage | Observatory of A Guarda, 1892–1893 |
| Quality | good |
| Redundancy | reports from the local newspaper “La Integridad” |

---

| Notebook IV | Typing | printed |
| Information format | tables, text |
| Legibility | clear |
| Informational | Data coverage | Observatory of A Guarda, 1891–1896 |
| Quality | good |
| Redundancy | reports from the local newspaper “La Integridad” |

---

doi:10.1371/journal.pone.0039281.t001
| Año  | Días  | 9 a. m. | 8 a. m. | 7 a. m. | 6 a. m. | 5 a. m. | 4 a. m. | 3 a. m. | 2 a. m. | 1 a. m. | Media | Mediana | tarde | Manana | Tardía |
|------|-------|---------|---------|---------|---------|---------|---------|---------|---------|---------|--------|---------|-------|--------|--------|
| 1891 | 18    | 7591    | 7461    | 7351    | 7221    | 7084    | 6968    | 6848    | 6721    | 6604    | 7591   | 7496    | 7401   | 7301   | 7201   |
|      | 2     | 7590    | 7460    | 7350    | 7220    | 7083    | 6967    | 6847    | 6721    | 6604    | 7590   | 7495    | 7400   | 7300   | 7200   |
|      | 3     | 7593    | 7463    | 7353    | 7223    | 7086    | 6969    | 6853    | 6726    | 6610    | 7593   | 7496    | 7401   | 7301   | 7201   |
|      | 4     | 7594    | 7464    | 7354    | 7224    | 7087    | 6970    | 6854    | 6727    | 6610    | 7594   | 7497    | 7402   | 7302   | 7202   |
|      | 5     | 7596    | 7466    | 7356    | 7226    | 7089    | 6972    | 6856    | 6728    | 6612    | 7596   | 7498    | 7403   | 7303   | 7203   |
|      | 6     | 7599    | 7469    | 7359    | 7229    | 7092    | 6975    | 6859    | 6731    | 6615    | 7599   | 7499    | 7404   | 7304   | 7204   |
|      | 7     | 7602    | 7472    | 7362    | 7232    | 7102    | 6982    | 6862    | 6734    | 6618    | 7602   | 7502    | 7405   | 7305   | 7205   |
|      | 8     | 7604    | 7474    | 7364    | 7234    | 7104    | 6984    | 6864    | 6736    | 6620    | 7604   | 7504    | 7406   | 7306   | 7206   |
|      | 9     | 7607    | 7476    | 7367    | 7237    | 7107    | 6986    | 6866    | 6739    | 6622    | 7607   | 7507    | 7407   | 7307   | 7207   |

**Figure 5.** Example of a typical page containing data from Notebook II [18].

doi:10.1371/journal.pone.0039281.g005
### Figure 6. Example of a table showing data split into periods of ten days of dominant winds and precipitation from Notebook III [19].

doi:10.1371/journal.pone.0039281.g006

### Figure 7. Example of a table showing data on precipitation measured by rain gauge from Notebook III [19].

doi:10.1371/journal.pone.0039281.g007
30 cm. The flora in the area around the observatory are also described.

The second part of this notebook contains meteorological data for the period 1894–6, including daily, monthly, seasonal and annual means. The variables recorded are the dominant wind direction, the wind strength, the cloud coverage and direction, the maximum, minimum and mean temperature, the mean pressure, relative humidity, mean vapour pressure, evaporation, rainfall and also daily subjective records of the observed weather conditions (e.g., “good weather”, “changing weather”, or “bad weather”).

**Results**

**Data Series Recovered and Digitized**

The data contained in the book are now available in Open-Document format [21,22], an open and accessible and internationally standard, freely accessible open format available on the internet. The data can be downloaded from: http://ephyslab.uvigo.es/documentos/AGuarda-recovered.ods.

We now list the recovered and digitized data series with the corresponding units where it is of application:

- **Notebook I, 1881–1890**
  - mean monthly pressure (mmHg) and temperature (°C), and corresponding maximum and daily oscillations
  - mean monthly relative humidity (%), vapour pressure (mmHg) and evaporation (mm)
  - total precipitation (mm) and number of rainy days
  - number of days with wind from each direction (N, NE, E, SE, S, SW, W, NW)
  - number of days with wind according to wind speed (calm, breeze, windy, strong)
  - general weather observations (tempest, hail, fog, cloudy, overcast, scatter, clear)

- **Notebook II, 1881–1890**
  - “extratropical cyclone days”
  - pressure (mmHg) for extratropical cyclone days
  - wind (N, NE, E, SE, S, SW, W, NW) direction for extratropical cyclone days

- **Notebook III, 1892–1893**
  - days of Moon phases
  - mean, maximum and minimum daily temperature (°C)
  - mean, maximum and minimum daily pressure (mmHg)

---

**Figure 8. Estimated precipitation for the valley and calories emitted, from Notebook III** [1].

doi:10.1371/journal.pone.0039281.g008
### Table: Temperatura en el Mes de Junio durante el quinquenio de 1891-1895

| Década 1.a | Promedio MAXIMA | Promedio MINIMA | Diferencia MAXIMA | Diferencia MINIMA | Promedio Temperatura Media | Temperatura a la Tierra | Promedio MAXIMA | Promedio MINIMA | Diferencia MAXIMA | Diferencia MINIMA |
|------------|----------------|----------------|-------------------|-------------------|--------------------------|------------------------|----------------|----------------|-------------------|-------------------|
| 1891       | 21.6           | 17.4           | 4.2               | 11.6              | 9.3                      | 5.7                    |                 |                 |                   |                   |
| 1892       | 29.1           | 23.1           | 6.0               | 14.1              | 11.9                     | 2.2                    | 18.0           | 9.0            | 9.0               | 9.0               |
| 1893       | 32.6           | 26.4           | 6.2               | 14.0              | 12.2                     | 2.0                    | 20.2           | 12.4           | 12.4              | 12.4              |
| 1894       | 26.5           | 20.1           | 6.4               | 12.8              | 10.8                     | 2.0                    | 16.4           | 12.4           | 12.4              | 12.4              |
| 1895       | 29.4           | 23.9           | 5.5               | 13.1              | 11.8                     | 1.3                    | 18.5           | 16.8           | 16.8              | 16.8              |
| Media      | 27.8           | 22.2           | 5.6               | 13.1              | 11.2                     | 1.0                    | 17.6           | 9.1            | 9.1               | 9.1               |
| Década 2.a |                |                |                   |                   |                          |                        |                 |                 |                   |                   |
| 1891       | 37.0           | 29.0           | 8.0               | 13.7              | 10.6                     | 3.1                    | 21.6           | 15.9           | 15.9              | 15.9              |
| 1892       | 28.4           | 21.7           | 6.7               | 12.2              | 10.4                     | 1.7                    | 16.0           | 9.6            | 9.6               | 9.6               |
| 1893       | 32.0           | 24.8           | 7.2               | 15.3              | 13.5                     | 1.8                    | 20.0           | 9.5            | 9.5               | 9.5               |
| 1894       | 22.7           | 25.9           | 5.8               | 13.3              | 11.0                     | 3.3                    | 19.6           | 12.6           | 12.6              | 12.6              |
| 1895       | 30.0           | 25.1           | 5.0               | 13.4              | 11.0                     | 1.5                    | 19.2           | 14.7           | 14.7              | 14.7              |
| Media      | 32.0           | 25.4           | 6.6               | 13.9              | 11.5                     | 2.1                    | 19.3           | 15.9           | 15.9              | 15.9              |
| Década 3.a |                |                |                   |                   |                          |                        |                 |                 |                   |                   |
| 1891       | 39.1           | 23.2           | 6.9               | 14.9              | 12.4                     | 2.5                    | 19.0           | 8.3            | 8.3               | 8.3               |
| 1892       | 36.7           | 25.0           | 5.7               | 15.2              | 13.4                     | 1.8                    | 20.1           | 9.8            | 9.8               | 9.8               |
| 1893       | 39.5           | 23.4           | 6.1               | 15.0              | 12.5                     | 1.7                    | 18.8           | 9.1            | 9.1               | 9.1               |
| 1894       | 32.0           | 25.3           | 6.7               | 15.6              | 13.4                     | 2.2                    | 20.4           | 9.7            | 9.7               | 9.7               |
| 1895       | 24.6           | 28.9           | 6.6               | 15.9              | 14.1                     | 1.8                    | 22.0           | 12.1           | 12.1              | 12.1              |
| Media      | 31.2           | 25.0           | 6.2               | 15.2              | 13.2                     | 2.0                    | 20.1           | 9.8            | 9.8               | 9.8               |
| Mes        | 30.3           | 24.2           | 6.1               | 15.0              | 11.9                     | 2.0                    | 19.1           | 10.2           | 10.2              | 10.2              |

Figure 9. Example of a table showing data from Notebook IV [20].

doi:10.1371/journal.pone.0039281.g009
**ESTACION METEROLÓGICA**  
**DEL**  
**COLEGIO DEL APÓSTOL SANTIAGO**  
де La Guardia.  
**Mes de Octubre de 1904.**

| Días del mes | Temperatura | Termómetro | Velocidad del Viento | Presión corregida | Viento | Nubes | Notas |
|--------------|-------------|------------|----------------------|-------------------|--------|-------|-------|
| 1            | 20.9        | 17.2       | 19.0                 | 17.8              | 17.3   | 14.0  | 95    |
| 2            | 20.8        | 12.4       | 16.6                 | 18.2              | 16.6   | 13.1  | 85    |
| 3            | 15.3        | 9.9        | 13.9                 | 15.4              | 13.0   | 9.7   | 75    |
| 4            | 25.9        | 14.2       | 20.0                 | 20.5              | 19.0   | 13.8  | 77    |
| 5            | 23.2        | 12.8       | 18.0                 | 19.8              | 17.1   | 12.9  | 75    |
| 6            | 21.0        | 12.6       | 18.8                 | 20.6              | 18.0   | 13.8  | 77    |
| 7            | 21.0        | 10.2       | 15.6                 | 19.8              | 17.0   | 12.7  | 74    |
| 8            | 20.2        | 8.9        | 14.5                 | 18.6              | 16.2   | 12.3  | 77    |
| 9            | 20.8        | 9.4        | 15.1                 | 17.4              | 15.0   | 11.2  | 76    |
| 10           | 21.4        | 10.0       | 15.7                 | 16.4              | 14.0   | 10.3  | 73    |
| 11           | 20.7        | 10.2       | 15.5                 | 15.5              | 13.2   | 9.3   | 71    |
| 12           | 21.2        | 9.4        | 15.3                 | 15.2              | 12.0   | 8.5   | 66    |
| 13           | 19.9        | 8.4        | 14.1                 | 15.0              | 13.2   | 10.2  | 80    |
| 14           | 19.0        | 9.2        | 14.1                 | 16.7              | 15.2   | 12.0  | 85    |
| 15           | 19.3        | 8.5        | 13.9                 | 16.8              | 14.2   | 11.8  | 84    |
| 16           | 19.5        | 8.0        | 13.8                 | 15.8              | 13.2   | 10.4  | 89    |
| 17           | 23.1        | 12.1       | 18.0                 | 17.4              | 15.8   | 12.1  | 82    |
| 18           | 22.7        | 11.1       | 18.9                 | 16.4              | 14.0   | 11.2  | 81    |
| 19           | 22.6        | 10.1       | 18.3                 | 16.8              | 14.2   | 10.4  | 73    |
| 20           | 19.3        | 10.1       | 14.7                 | 16.8              | 14.8   | 11.0  | 77    |
| 21           | 17.8        | 9.6        | 13.7                 | 14.8              | 14.0   | 11.4  | 91    |
| 22           | 15.7        | 12.1       | 15.4                 | 16.8              | 15.3   | 12.1  | 85    |
| 23           | 21.5        | 12.2       | 17.0                 | 20.0              | 19.0   | 12.7  | 63    |
| 24           | 24.4        | 17.8       | 21.1                 | 22.4              | 20.0   | 14.5  | 84    |
| 25           | 25.2        | 15.8       | 21.0                 | 20.0              | 19.2   | 13.6  | 71    |
| 26           | 26.0        | 16.3       | 21.1                 | 21.4              | 17.5   | 14.8  | 98    |
| 27           | 21.2        | 15.4       | 18.3                 | 18.0              | 15.0   | 13.8  | 89    |
| 28           | 20.3        | 13.9       | 17.1                 | 16.5              | 16.0   | 11.1  | 78    |
| 29           | 19.7        | 14.1       | 18.9                 | 18.6              | 16.2   | 12.3  | 77    |
| 30           | 18.9        | 14.3       | 18.7                 | 17.7              | 15.5   | 11.9  | 79    |
| Media        | 21.3        | 11.7       | 16.5                 | 17.7              | 15.5   | 11.9  | 79    |

El Encargado de la Estación.  
P. B. Marroño S. J.
temperature in the shade and in the sun (°C)
- daily wind speed (between 0 and 3) and direction (N, NE, E, SE, S, SW, W, NW)
- daily relative humidity (%), vapour pressure (mmHg) and evaporation (mm)
- total precipitation (mm)
- cloud cover (between 0 and 2)
- general weather observations (good weather, changing weather, or bad weather)

**Notebook IV, 1894–1896:** similar to Notebook III, but also includes values of pressure, relative humidity and vapor pressure at 0900 and 1500 UTC.

### Data Series Recovered and Not Digitized

As an additional outcome of our research, we also unearthed other documentary sources that could soon contribute to the expansion of the data series thus far recovered and digitized. These are data obtained from Father Orcolaga and the newspaper La Integridad.

In the first case, we unexpectedly found a new documentary source at the Observatori de l’Ebre. Father Orcolaga, head of the observatory of Igeldo (Donosti, Spain) received daily reports by telegraph of the data measured at A Guarda, beginning in October, 1904. These reports included data on temperature (in °C) (maximum, minimum and mean), vapour pressure, relative humidity, wind speed and direction, cloud type, cover and direction, precipitation, together with annotations describing how to classify the meteorological conditions for each day. The data were measured at 0900 UTC for the period from October 1904 to April 1905, and at 0700 UTC from May 1905 to May 1906. An example of this source of data is given in Table 2 and Figure 10.

Secondly, we recently located a collection of microfilms of local newspaper no longer in circulation called “La Integridad” (Figures 11 and 12) in the library of the Universidad de Santiago.

| Formal | Source format | Photocopy |
|--------|---------------|-----------|
| Information type | numeric, text |           |
| Information format | tables, text |           |
| Typing | printed |           |
| Legibility | clear |           |
| Informational Data coverage | Observatory of A Guarda, 1904–1906 |           |
| Quality | good |           |

doi:10.1371/journal.pone.0039281.t002
Following a preliminary analysis, it is apparent that daily or weekly meteorological reports obtained from the observatory of A Guarda were occasionally published in this newspaper. However, we have not been able to complete the recovery and digitization of these reports to date. Table 3 gives a description of this source of data. These reports, known as ‘‘Meteorografía’’, include mean daily pressure, temperature, daily maximum and minimum temperature, temperature in the sun, maximum and minimum soil temperature at a depth of 30 cm, mean vapour pressure, mean relative humidity, wind speed and direction, subjective weather (cloudy, etc.), rate of soil cooling, precipitation, evaporation and a value of ozone measured. As it can be seen in Figure 12 no units are indicated.

Comparisons

In order to assess the validity of the data recovered, we performed a comparison using data for the periods 1971–2000 and 2001–2009. We compared the mean monthly temperature, pressure and total precipitation, the number of extratropical cyclones and the monthly mean pressure for extratropical cyclones.

In Figure 13, we compare the monthly total precipitation, monthly mean temperature and pressure and corresponding standard deviation for the periods 1881–1890 (i.e., the recovered data), 1971–2000 (Peinador) and 2001–2010 (the Monte Aloia series). It may be seen that precipitation follows a very similar pattern for the three periods with minimum values in July-August. The values for the two most recent periods closely resemble each other and are generally higher than those for the period of data recovered. The intrannual variability of temperature is extremely similar for both the recovered data and the present data following the typical pattern for extratropical latitudes of the northern hemisphere. The profiles of pressure show the higher corresponding to the hemispheric winter. This is probably a result of the Azores Anticyclone, which is predominant over the region of interest during this season. Its displacement to the Bermudas during the hemispheric summer is probably the cause of the lower mean values of pressure. For 1881–1990 and 1971–2000 the annual minimum pressure occurs in April and for 2001–2010 in July. The absolute values of pressure of A Guarda and Peinador are not comparable with Monte Aloia, but this is simply because of the difference in height between the three stations. The possibility of addressing this by reducing the pressure at Monte Aloia to sea level was not considered feasible, because the the temperature series needed to do this did not have the same temporal homogeneity as the pressure series.

A comparison of the extratropical cyclones shown by the three datasets is not a straightforward matter. From the notebooks, it is not clear what Father Merino considers to be an extratropical cyclone. After careful checking of the data, we conclude that it is possible to link the data on extratropical cyclones with a value of pressure. Furthermore, Father Merino seems to state that whenever there is an extratropical cyclone, the wind is at least ‘‘fuerte’’ (strong) or ‘‘ventoso’’ (windy) and sometimes ‘‘tempestad’’ (a tempest). Moreover, in different parts of the notebooks the clear days for A Guarda are linked with values of pressure in excess of 760 mmHg, while 750–760 mmHg corresponds to variable weather, 740–750 mmHg corresponds with windy days, 730–740 mmHg corresponds with strong wind days, and values below 730 mmHg correspond with stormy weather. In attending to these criteria and checking the values, we conclude that 755 mmHg represents a better threshold for considering a day to be affected by an extratropical cyclone. We therefore herein consider an extratropical cyclone to be present for those days with values of pressure less than 755 mmHg (approx. 1006.58 hPa) both for A Guarda and Peinador, where we have data of pressure at sea level. By taking into account the difference in elevation between A Guarda and Monte Aloia, we calculate the corresponding
Figure 13. Monthly total precipitation, mean temperature and mean pressure and corresponding standard deviations for the observatory of A Guarda, Monte Aloia and Peinador.

doi:10.1371/journal.pone.0039281.g013
threshold pressure for Monte Aloia using the relationship given by Iribarne and Godson [23]:

\[ p = \frac{1013.25 - 2.255 \times 10^{-5}H^{2.256}}{} \]

where \( p \) is the pressure in hPa and \( H \) is the altitude in meters. The result is a difference of 56.79 hPa, and we therefore consider extratropical cyclone days for Monte Aloia to be those with pressures less than a threshold value of 949.79 hPa. Figure 14 shows a comparison of these days for the three periods. The three records mostly agree in the shape of the intra-annual variation and in some cases in the actual values. It is important to note how the result values for Peinador mostly agree with those for Monte Aloia and perfectly fit in some cases, which validates the results obtained computing the corresponding sea level pressure. Differences can be because of singular years with an unusual number of extratropical cyclones. This result confirms our correct interpretation of the data contained in the notebooks, and we were therefore able to use them in further comparisons.

Figure 15 shows the intra-annual variation of the mean pressure, using only those days classified as “extratropical cyclone days”. The number of extratropical cyclones used to compute it can be easily followed from Figure 14. The minimum value occurs in 1881–1890 is in April, as for the mean monthly pressure shown in Figure 13. Moreover, for both the recovered series and that obtained from Monte Aloia and Peinador, a steady decrease in pressure may be seen from August to December. As expected, the maximum values of pressure are seen in the hemispheric summer.
There were no “extratropical cyclone days” in July at Monte Aloia and just one in Peinador which makes the minimum in pressure less significant than the one for April.

Discussion

We have herein presented our attempts to recover old instrumental data from documentary sources for the period 1881-96. We have digitized the data series and made them available to the scientific community. We have also compiled an exhaustive set of metadata describing the observatory and its instrumentation. This recovery effort for the northwestern Iberian Peninsula has been entirely worthwhile, as may be seen from our comparisons with more recent data, and wholly relevant for the region of interest, in view of the influence of such phenomena as the North Atlantic Oscillation.

The importance of records of ozone in reports contained in La Integridad cannot be overstated; these measurements are not common for the period described here and only a few previous studies have reported similar data for other locations [24–26]. It is also most interesting to note the explanation of a procedure for measuring such chemicals as chlorine and ammonia; these reveal the particularly astute observations of Father Merino in his meteorological analysis.

It is unfortunate that the way in which the data were originally reported in the notebooks does not allow more complete climatological comparisons to be made. Nevertheless, it is apparent that they represent a valuable source of information, for example for the study of the timing of extreme meteorological events or for the completion of existing data recovery efforts.

Acknowledgments

The authors would like to thank Maria Genescá from the Observatori de l’Ebre and Ricardo García-Herrera from the Universidad Complutense de Madrid, for helping them obtain important documentation and the originals of the notebooks. The meteorological data for the Monte Aloia station were obtained from the website of the Consellería de Medio Ambiente, Territorio e Infraestructuras (Regional Government of Galicia). We acknowledge the data providers in the ECAD project. We thank to three anonymous reviewers and the editor for their helpful comments.

Author Contributions

Conceived and designed the experiments: JAA LG LdT. Performed the experiments: JAA MBD. Analyzed the data: JAA MBD LdT. Wrote the paper: JAA LG LdT. Digitized the data: MBD.

References

1. Brömimann S, Amin J, Daan W, Ewen T, Grant AN, et al. (2006) A guide to digitising manuscript climate data. Clim Past 2: 137–144.
2. WMO (2004) Guidelines on Climate Data Rescue. WMO/TD No. 1210. Technical report, Geneva, Switzerland.
3. WMO (2008) MEDARE: Proceedings of the International Workshop on Rescue and Digitization of Climate Records in the Mediterranean Basin. WCDMP No. 67, WMO/TD No. 1432. Technical report, Geneva, Switzerland.
4. ACRE (2010) The ACRE Initiative (The International Atmospheric Circulation Reconstructions over the Earth). Available: http://www.met-acre.org/. Accessed 2012 Jun 12.
5. Jones P, Jonsson T, Wheeler D (1997) Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. Int J Clim 17: 1433–1450.
6. Hurrell J (2003) Climate Variability: North Atlantic and Arctic Oscillation, Academic Press, volume 2. 439–445.
7. Trigo R, Valente M, Trigo I, Miranda P, Ramos A, et al. (2008) The Impact of North Atlantic Wind and Cyclone Trends on European Precipitation and Significant Wave Height in the Atlantic. Ann N Y Acad Sci 1146: 212–234.
8. García-Herrera R, García RR, Prieto MR, Hernández E, Gimeno L, et al. (2003) The Use of Spanish Historical Archives. Bull Amer Meteor Soc 84: 1025–1035.
9. Rodrigo FS, Barriendos M (2008) Reconstruction of seasonal and annual rainfall variability in the Iberian peninsula (16th-20th centuries) from documentary data. Global Planets Change 63: 243–257.
10. Udías A (1996) Jesuits’ contribution to meteorology. Bull Amer Meteor Soc 7: 2307–2313.
11. Udías A (2003) Searching the heavens and the Earth: the history of Jesuit observatories. Berlin: Kluwer Academic Publishers. 369.
12. Trigo RM, Pozo-Vázquez D, Osbom TJ, Castro-Diez Y, Gámiz-Foris S, et al. (2004) North Atlantic Oscillation influence on precipitation, river ow and water resources in the Iberian Peninsula. Int J Clim 24: 923–944.
13. García NO, Gimeno L, de la Torre L, Nieto R, Atel JA (2005) North Atlantic Oscillation (NAO) and precipitation in Galicia (Spain). Atmosfera: 25–32.
14. Servicio Meteorologico Nacional (1943) Las series más largas de observaciones pluviométricas en la Península Ibérica. Serie D (Estadísticas) N 1.
15. Blanco-Durán M, Atel JA, Gimeno L (2000) O observatorio da Guarda. In: Consello da Cultura Galega, editor. Historia da Meteroloxia e Climatoloxia de Galicia. 209.
16. Merino B (1891) Resumen de las observaciones meteorológicas efectuadas en el Colegio de La Guardia, de la Compañía de Jesús, durante el decenio de 1881 a 1890, indicaciones sobre el clima de aquella localidad. Observatorio de Madrid.
17. Klein Tank AMG, Wijngaard JB, Köenig GP, Bohm R, Deranne G, et al. (2002) Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int J Clim 22: 1441–1453.
18. Merino B (1893) Estudio sobre las borrascas en la costa occidental de Galicia. Toxi, Spain: Tipografía Gallega. 6s.
19. Merino B (1894) Observatorio Meteorológico del Colegio de la Compañía de Jesús en La Guardia. Cuaderno Tercero. Tui, Spain: Galicia Typography.
20. Merino B (1897) Observatorio Meteorológico del Colegio de la Compañía de Jesús en La Guardia. Cuaderno Cuarto. Tui, Spain: Regional Typography.
21. OASIS (2005) Open Document Format for Office Applications (OpenDocument) v1.0. Technical report.
22. Eisenberg JD (2005) OASIS OpenDocument Essentials, Friends of OpenDocument Inc. 293 p.
23. Irbarne JV, Godson WL (1996) Termodinámica de la Atmósfera. Madrid, Spain: Ministerio de Medio Ambiente. 296.
24. Linville D, Hooker WJ, Olson B (1980) Ozone in michigan’s environment 1876–1880. Mon Wea Rev 108: 1803–1891.
25. Cantalis C, Vatosos C (1994) Surface ozone in athens, greece, at the beginning and at the end of the twentieth century. Atmos Environ 28: 3–8.
26. Vatosos C, Kalabokas P, Vlassi A, Katsovas A, Stratigos J, et al. (1994) The biologically active ultraviolet radiation in relation to the surface ozone and the wind field. Tox Environ Chem 44: 233–242.