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A new meteorological record for Cádiz (Spain) 1806–1852: Implications for climatic reconstructions

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[1] A new documentary source of data for wind, atmospheric pressure and air temperature for the city of Cádiz (southern Spain) has been abstracted, analyzed and compared with present-day data. Wind records cover the period 1806–1852 with three observations per day. Instrumental pressure and temperature cover the period 1825–1852. While the historical pressure series shows average values very close to that found for the period 1971–2000, temperature shows a large asymmetric seasonal warming, with increments in the order of 2°C for the winter months and almost no change for summer. Wind measurements have been transformed into their numerical equivalents and then compared with present-day values. The analysis shows that the numerical estimation of ancient wind forces observed at Cádiz, while providing a robust climatic signal, has a strong bias to larger values than their instrumental equivalents. Despite the uncertainties involved in the interpretation of early wind series, this effect could be related to the recording of "average wind gusts" rather than average winds as measured by today's anemometers. In consequence, wind climatologies based on historical data, which recently are becoming available to the scientific community, should be used carefully.

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1. Introduction

[2] During the last decades, the growing evidence of an anthropogenically induced climatic change [*Intergovernmental Panel on Climate Change*, 2007] and the need to compare present-day climate with that of the past centuries, has boosted the search of long series with the highest available accuracy and resolution. Unfortunately, when going back in time, the number of available data recorded at daily scale decreases drastically. The necessity of long series has triggered a worldwide effort aimed to unveil early meteorological data from all kind of historical archives. The role of Europe in introducing daily continuous observations into the meteorological practice is the reason why most of the earlier and longer series have been found in this continent [e.g., *Wheeler and Martin-Vide*, 1992; *Parker et al.*, 1992; *Wheeler*, 1995; *Jonsson and Fortuniak*, 1995; *Jonsson and Gardarsson*, 2001; *Rodriguez et al.*, 2001; *Slonosky et al.*, 2001; *Demaree et al.*, 2002; *Cocheo and Camuffo*, 2002; *Barriendos et al.*, 2002; *Können and Brandsma*, 2005]. Major projects, such as IMPROVE, have focused on generating homogeneous databases of instrumental data [*Camuffo and Jones*, 2002].

[3] The vast majority of early meteorological data consist of measures of atmospheric pressure, temperature or precipitation. Over Spain, a number of long instrumental series for these variables have been found. The reader is referred to *Ansell et al.* [2006] and *Brunet et al.* [2006] for an updated review of the available instrumental data in Spain for pressure and temperature respectively. On the contrary, despite the known existence of long wind series, wind data have been barely used for periods prior to 1900. The currently available wind series going back to the 18th and 19th centuries essentially consist of semi-quantitative wind directions series [*Jonsson and Fortuniak*, 1995; *Wheeler*, 1995]. The main reason is that for most of the 19th century, anemometers were scarcely used and although in the early meteorological observatories wind was routinely estimated and archived, the data were recorded in nonstandard and nonnumerical scales.

[4] Many of the first meteorological observatories were located along coastlines. Cádiz, in southern Spain (Figure 1) was one of the major European harbors during the 18th and 19th centuries because of its predominant commercial role with the Spanish American territories. Simultaneously, the city showed a flourishing of cultural and scientific activities. In particular, the Real Observatorio de Cádiz (Royal Observatory of Cádiz) established in 1751, and later moved to the nearby city of San Fernando, had an early civic interest in natural sciences. As a result, the city of Cádiz possesses one of the longest meteorological series in Iberia. It consists of a blended series based in several archives in Cádiz and San Fernando that can be traced back to 1786 [*Barriendos et al.*, 2002].

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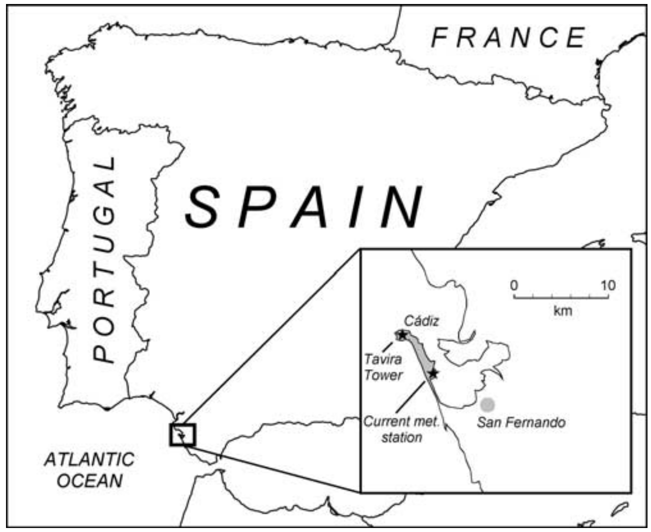

Figure 1. Location of Cádiz. The positions of the Tavira Tower and the current meteorological station are displayed in the detailed area.

This series (referred as CSF in successive) is constructed exclusively with Cádiz data between 1816 and 1870. However, the absence of metadata for this period introduces some uncertainty in its values, especially for pressure, as noted by *Vinther et al.* [2003], thus making desirable the finding of new weather sources for this period. Fortunately, the activities related with the Cádiz port led to the generation of alternative weather observation systems. In 1778 an official meteorological observatory was created in a building called "Tavira tower" under the Navy management. This tower, currently used as a museum, was designated the official watchtower of Cádiz because of its strategic location in the middle of the Old City, one of the highest points in the extremely flat terrain of Cádiz, with a height of 12 m.a.s.l. The merchant ships movements in the port were reported through a daily local journal called *Partes de la Vigía*, which can be translated as "Watchtower Reports." This publication was distributed among local merchants under subscription. Since 1806 these reports included data on direction and wind force and the general state of weather and sky. These early measures were essential for the safety of the ships in a notoriously hazardous harbor to get in and out of as Cádiz, a fact that is acknowledged even today. In 1825 daily instrumental observations of pressure and temperature were included.

[5] The aim of this paper is double: first, to uncover the new instrumental data for temperature and pressure, comparing the records both with the CSF series and present-day values; second, to test the climatic signal of the secularly underused wind descriptors employed to record wind force and direction in the 19th century. The paper is organized as follows: section 2 describes the new data source and the methodology used to translate the information to standard units. The Cádiz climatology based in the new source is developed in section 3, including a comparison both with present-day data and previous historical climatologies for Cádiz. Finally, section 4 discusses the results and its importance for future reconstructions based in similar methodologies.

2. Data and Method

[6] Most of the original Watchtower Reports containing the meteorological information taken in the Tavira Tower have survived in the *Biblioteca de Temas Gaditanos* "*Juvencio Maeztu*" ("Juvencio Maeztu" Library on Cádiz Topics), which keeps bounded volumes of the reports of the period 1789 to 1940, with a gap due to unknown reasons between 1853 and 1890. Because of funding limitations, the abstraction period has been limited to the earliest part of the series containing meteorological information (1806–1852). The meteorological records included in the volumes for this period have been digitized and introduced in an electronic database. Data from 1890 to 1940 remain still unexplored. Two main sets of data were digitized, instrumental records for temperature and pressure and noninstrumental records for wind force and direction.

2.1. Temperature and Pressure Records

[7] Both series began in 1825 (Figure 2) with two major gaps for the entire years 1831 and 1837 and one minor gap

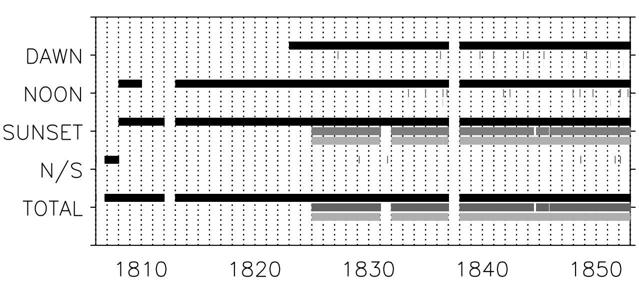

Figure 2. Temporal coverage of the wind measures (black), instrumental atmospheric pressure (dark grey) and instrumental temperature (light grey) in the Watchtower Reports. (N/S stands for "not specified.")

during 1844 for temperature. With few exceptions, temperature and atmospheric pressure were recorded exclusively at sunset with a total of 9466 and 9349 records respectively. Unfortunately, in most of the cases there are no metadata indicating neither the kind of thermometer or barometer, their precise location in the tower or even the measurement units.

[8] After a preliminary inspection, it was evident that the instruments in use were of French origin. Temperature was always measured in the Reaumur scale (degrees and 1/10th of degree), similarly as it was done in the neighbor observatory of San Fernando before 1870 [*Barriendos et al.*, 2002]. In the vast majority of the cases, the atmospheric pressure units are not specified but there were three main, and substantially different, air pressure units in use during the first half of the 19th century in Spain: French, English and Castilian inches, equivalent to 27.0696, 25.3995 and 23.2195 Hg mm respectively [*Rodriguez et al.*, 2001; *Barriendos et al.*, 2002]. Most of the values are only consistent with French inches and are expressed in inches, lines and fraction of line (being a line 1/12th of an inch), the usual structure of the pressure expressed in this unit in Spain at the time. For unknown reasons, between 9 January 1840 and 6 August 1840 pressure is given in English inches (inch and 1/100 inch), being these the only cases in which the units are explicitly specified.

[9] The original documents do not provide information about the corrections, if any, originally applied to the pressure records. Neither the precise height of the barometer nor the inclusion of the attached temperature correction are ever specified, but the barometer was most probably located in the position of the watchman at 33 m above the ground, which added to the 12 m of the terrain accounts for 45 m.a.s.l. (C. Camacho, personal communication, 2006). After converting the records to hPa, applying the specific gravity correction for Cádiz and reducing the value to sea level, quality control procedures showed a number of dubious sea level pressure (SLP) data evidenced by unusually high or low values, typically related to strong discontinuities in the pressure evolution (sudden drops or rises in the order of 20 to 30 hPa). The analysis of the original data showed no evident causes for these anomalies, which are probably related to erratum in the original reports. As a conservative measure, the series was filtered by considering SLP values below/above the percentile 1%/99% as missing data.

2.2. Wind Records

[10] A total of 41428 wind records spanning the period 1806 to 1852 at subdaily resolution for wind force and direction were digitized. Their availability according to the calendar year and part of the day is displayed in Figure 2. The first wind records began on 16 October 1806 with a single observation per day. Up to 1808, the part of the day at which the measurement was taken was not specified, but most probably they were made at noon. From 1808 to 1823 two daily observations at noon and sunset were recorded. From 1 January 1823 on, the observation and dawn was also included. Data for the complete years 1812 and 1837 are missing.

[11] Wind observations during the first half of the 19th century were not recorded in a numerical way but in textual form using descriptors. Nowadays the wind measure and codification in textual form is still in use through the Beaufort wind scale. This scale was the result of a long and international evolution of wind force terms used aboard sailing ships developed since the 16th century. In fact, by 1800, long before the adoption of the scale in Europe, most of the wind force records already followed an analogous structure of that of the 13-point wind force scale subsequently rationalized by Beaufort [*Wheeler and Wilkinson*, 2005; *Koek and Können*, 2005]. Despite the relatively high degree of standardization, it must be kept in mind that up to the mid 1850s and even as late as the beginning of the 20th century, depending on the country, there were no formal rules to record wind force. In Spain the use of the Beaufort scale gradually began during the second half of the 19th century and in consequence the Watchtower Reports for the period covered in this work do not follow strictly the Beaufort standards. As in the rest of Europe, in spite of the relatively high number of wind descriptors, the wind force measurements taken by navy-trained personnel were already codified according to unwritten rules very similar to the Beaufort scale. By analyzing the language and the historical context, it is possible to reduce the number of descriptors and even to convert these early wind measurements in an estimation of its modern numerical equivalents (see *Prieto et al.* [2005] for a complete discussion). It must be emphasized that these considerations apply to the wind force. Wind direction was recorded in a 16-point compass (though strongly biased to the use of 8-point compass) not being necessary to apply any correction with the occasional exception of that related to the use of the magnetic, instead of the geographical north [*Wheeler and Wilkinson*, 2005].

[12] Between the years 2001 and 2003, the CLIWOC project (Climatological Database for the World's Oceans [see *García-Herrera et al.*, 2005a]) undertook an unprecedented effort aimed to digitize and analyze wind terms taken aboard European sailing ships between 1750 and 1850, preserved to our time inside the ship's logbooks kept in several European archives. Two of the outputs of the project were the realization of the high precision and uniformity of the wind force terms used by the European Navy-trained observers, which were more reliable and consistent than previously thought and, second, the generation of an international dictionary (subsequently referred as "CLIWOC dictionary") containing a direct translation of the archaic wind force terms included in Spanish, French, Dutch and British logbooks to the modern day Beaufort-scale equivalents, directly convertible in estimations of the wind speed [*Climatological Database for the World's Oceans* (*CLIWOC*) *Team*, 2003]. The details of the original logbook data and the conversion methodology are given by *García-Herrera et al.* [2005b], *Koek and Können* [2005], *Prieto et al.* [2005] and *Wheeler and Wilkinson* [2005].

[13] The applicability of the CLIWOC dictionary, developed for the maritime terms used aboard ships, to the land-based watchtower wind series is not a trivial issue (see section 4). However, it must be kept in mind that the personnel in charge of the measures in the Tavira Tower were trained by the Navy and they followed the same rules for the wind codification as those in use aboard ships. A preliminary exploratory analysis showed that the terms used were of the same nature as those found in the contemporary ship's logbooks. This fact was confirmed

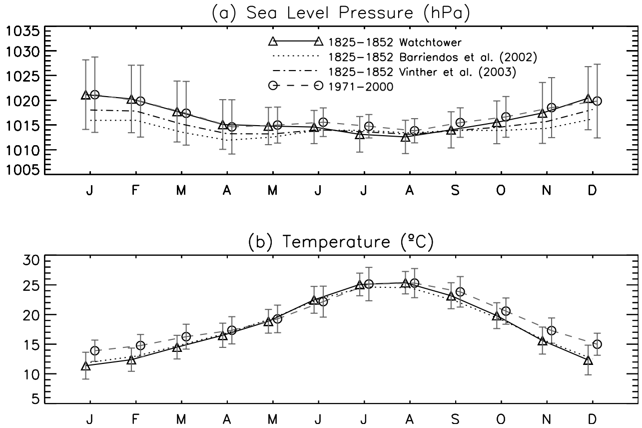

Figure 3. Sunset (a) SLP and (b) temperature for the Watchtower Reports (triangles, solid line), *Barriendos et al.* [2002] reconstruction for the same period (dots) and 1971–2000 climatology (circles, dashed line). For the SLP the correction of *Vinther et al.* [2003] to the *Barriendos et al.* [2002] series has been also displayed (dash-dot). Error bars indicate ±1 standard deviation for the monthly averages for the Watchtower Reports and the 1971–2000 climatology.

when the CLIWOC dictionary was applied to the watchtower data, being possible to convert directly 99.87% of the original records into their Beaufort equivalent and then into m s^{-1}. The unclassified records were minor variations, mostly related to the occasional inclusion of the term "en bahia" ("at the bay") explicitly stating the place at which the observation was referred. This term does not change the meaning of the wind force descriptor and usually was simply omitted.

2.3. Present-Day Data

[14] In order to compare the watchtower records with a present-day climatology, data from the Spanish National Weather Service at the current Cádiz meteorological observatory (36°29′55N; 6°15′37W and 8 m.a.s.l.) has been used. While this meteorological station is located about 5 km southwest of the Tavira Tower (see Figure 1), it is the closest current station with a longer enough subdaily resolution series. Daily records of temperature, atmospheric pressure and wind for this station started on 1 January 1956 for the 0700, 1300 and 1800 (UTC) observations. By 1967 the observation at 0000 UTC was also included. As the watchtower measurements were taken at sunset, for comparison purposes, present-day data for temperature and pressure have been interpolated to a simulated sunset value using the 1800 UTC value and the 1300 or the 0000 UTC (following day), depending on the sunset time. Although this approach provides a comparable time for both set of observations, it limits the period of useful present-day data, which has been set to the climatological 30-year standard period 1971–2000.

3. Watchtower Climatology

3.1. Pressure and Temperature

[15] Watchtower SLP values agree remarkably well with the 1971–2000 data between October and May, both in average and variability (Figure 3a). During summer, the average SLP for the 1825–1852 period exhibits values up to 1.5 hPa (July and September) lower than those observed in 1971–2000. This fact suggests the inclusion of the attached temperature correction in the original watchtower data, which otherwise should display higher than present-day values during summer. The inclusion of this correction was not infrequent in contemporary Spanish series (M. Barriendos, personal communication, 2006).

[16] Comparison with the equivalent CSF series for the 1825–1852 period yields a day to day correlation between SLP anomalies of 0.72 ($p < 0.01$). This correlation is rather stable along the year for autumn (SON; $r = 0.67$, $p < 0.01$), winter (DJF; $r = 0.81$, $p < 0.01$) and spring (MAM; $r = 0.78$, $p < 0.01$) but drops to 0.20 ($p < 0.01$) during summer (JJA), when SLP in Cádiz is more stable and differences in SLP anomalies between both series becomes more important in relative terms. Despite the similar variability, Figure 3a shows that the monthly SLP averages are between 2 and 5 hPa lower for the CSF series, with the exception of the summer months. In this regard, as part of a work aimed to improve the earlier part of the North Atlantic Oscillation (NAO) instrumental record of *Jones et al.* [1997], *Vinther et al.* [2003] carefully evaluated the CSF series by comparing it with the nearby series of San Fernando [*Barriendos et al.*, 2002] and Gibraltar [*Jones et al.*, 1997]. They concluded that between 1821 and 1869, most probably the CSF series suffered a lack of correction for attached temperature and a bias between −5.4 and −0.9 hPa, depending on the year. When these corrections are included the differences with the watchtower records are reduced by a factor of 2 (see Figure 3a) but the corrected CSF series still lays below the present-day values or the watchtower data.

[17] The uncertainties involved in the measure of the pressure difficult the interpretation of the differences. Both historical series present large uncertainties in the location of the barometer. For the CSF series we do not know even the location of the instrument in the city and for the watchtower data, the altitude of the barometer has been supposed on the basis of the location and height of the Tavira Tower. Moreover, in both cases, as no metadata are available, the only means of correcting the pressure data by attached temperature is to use the outdoor temperature, which could not be representing the temperature of the barometer. Finally, the present-day data are only representative of a 30-year period known to display slightly larger SLPs than longer-term averages, as evidenced by the well-documented tendency of the NAO to positive values during the last decades of the 20th century [*Hurrell et al.*, 2001]. It must be stressed that while watchtower data seem to better reproduce the average values and the seasonal cycle currently observed, they present a larger number of missing and dubious values (11.0%) than the CSF series (0.1%).

[18] The temperature record (Figure 3b) shows two remarkable features. First, the comparison between the watchtower and the 1971–2000 data shows that, while summer temperatures have experienced little changes, a notable increase in average temperatures is evident for the rest of the year and especially during winter. Sunset temperatures for 1825–1852 show values between 2.4°C and 2.7°C lower relative to the 1971–2000 period from December to February. T-test results show statistically significant higher

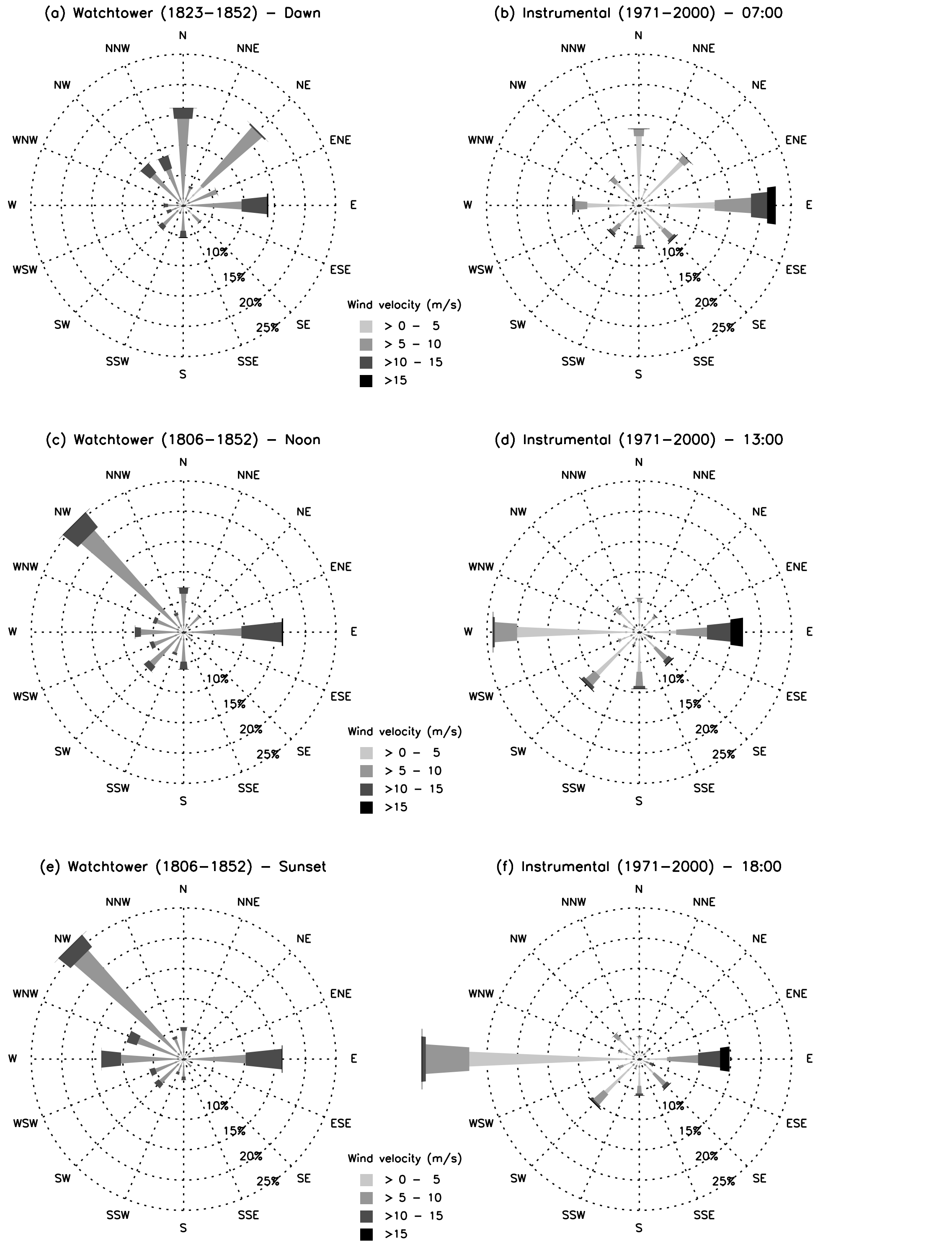

Figure 4. Compasses of the reconstructed wind for (left) the Watchtower Reports and (right) the 1971–2000 period. Contributions of the different wind forces are indicated by the color and width of the bars.

temperatures for present-day data ($p < 0.01$) between September and May. Second, unlike the pressure series, both historical records for the temperature of Cádiz show a very similar seasonal cycle for the period 1825–1852 and a temporal correlation between day-to-day temperature anomalies rather high ($r = 0.81$, $p < 0.01$). The main difference of both historical series consists in the larger annual range of the watchtower data. With summer/winter temperatures of the watchtower records slightly warmer/cooler than the CSF series for the same period.

3.2. Wind Climatology

[19] Figure 4 shows the wind compasses for the Watchtower Reports and the 1971–2000 period for every part of

Table 1. Ten Wind Descriptors Most Frequently Included in the Watch Tower Reports (1806–1852)[a]

Original Descriptor	Relative Frequency, %	Beaufort Equivalent	Assigned m s^{-1}
FRESQUITO	50.1	5	9.3
BONANCIBLE	25.2	4	6.7
FRESCO	16.7	6	12.3
VENTOLINAS	5.6	1	1
CALMA	0.8	0	0
MUY FRESQUITO	0.5	5	10
MUY FRESCO	0.3	7	15.4
ALGO FRESQUITO	0.2	5	8.7
CALMOSO	0.1	2	2.6
BIEN FRESCO	0.1	6	12.3

[a]The Beaufort equivalent and the assigned average velocity are indicated (see *CLIWOC Team* [2003] for details on this conversion).

day. Because of the high variability of the wind, in this case no interpolation has been performed in the present-day data to estimate the dawn or sunset value, and in consequence, the time of the observation is not exactly the same for each data set.

[20] In general, the compasses show two prevalent wind directions (E and W/NW depending on the set), according to the Cádiz location close to the Strait of Gibraltar, which acts as a natural wind channel. The great frequency of the easterlies is observed in both data sets. This wind direction also shows the greatest strengths. In both sets, the early hours of the day show higher direction variability, with northeasterly components clearly dominant, while as the day advances, the frequency of the westerly component becomes more important.

[21] Two main differences between early and current data are evident. First, while for the 1971–2000 period the most frequent wind at noon and sunset shows a pure westerly component, watchtower data evidences a dominant north-westerly direction. Because of the extreme dependence of the wind direction on the precise location of the observatory, it is not possible to discern whether this relatively small disparity in direction arises from a real change in the wind regime or the particular location of the current meteorological station, situated at the end of a 3-km long northwesterly oriented natural channel between the Cádiz peninsula and the mainland (Figure 1). The second and most important difference concerns the distribution of wind velocity. In general, watchtower data show higher frequencies for the larger categories and a lower resolution. This is most evident in the virtual absence of watchtower records with velocities in the category of the lowest winds (light grey, winds up to 5 m s^{-1}) (Figures 4a, 4c and 4e), while 1971–2000 data exhibits its maximum frequencies usually for this category (Figures 4b, 4d and 4f). The lower resolution is a direct consequence of the nature of the data. While a complete discussion on this issue is out of the reach of this paper [see *Prieto et al.*, 2005], in essence the problem arises from the relatively low number of wind descriptors with a significant frequency in the original reports (Table 1). 97.6% of the wind measures correspond to four different wind descriptors and nearly 50% were codified as "Fresquito," equivalent to a category 5 (fresh breeze) in the Beaufort wind scale and being converted as 9.3 m s^{-1}. There is not a significant number of wind descriptors with low Beaufort numbers 2 and 3. The frequency of calms is under 1%, well below present-day estimations (7%).

[22] The larger values of the watchtower wind series are further evident when comparing the monthly averages of both data sets at different parts of the day (Figure 5). Despite the nearly double value of the watchtower estimates compared to the present-day averages, the seasonal variations match remarkably well, especially at dawn and noon. Winter sunrises in Cádiz are currently slightly windier than summer ones and the same was observed back in the second quarter of the 19th century. On the contrary, solar heating tends to result in a windier midday in summer, while spring and autumn sunsets show two small wind maxima in both data sets. Related with the wind force variability, the evident underestimation of the wind variability (error bars in Figure 5) is a clear artifact of the conversion method, which leads to a "discretization" of the translated wind force series.

[23] Finally, Figure 6 shows the annual averages of the reconstructed wind record for Cádiz for the complete study period. The average wind force varies between 8 and 10 m s^{-1}, with the decade of 1830s showing the largest values. The intra-annual variability seems lower for sunrises, but as it was suggested in the last paragraph, the conversion methodology results in discrete wind values and does not permit the precise quantification of the wind force variability. While this time series values almost double its instrumental counterpart (figure not shown) they are rather stable in time, suggesting the constancy of the observation

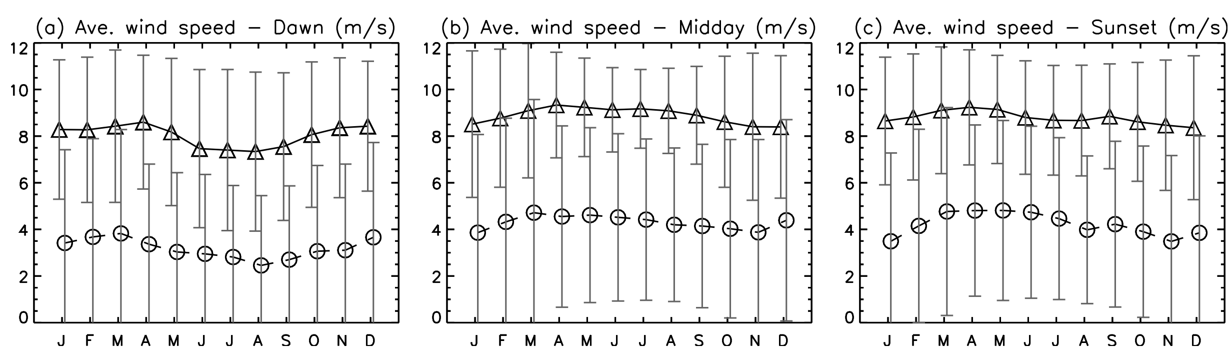

Figure 5. Seasonal cycle for the Watchtower Reports wind (triangles, solid line) and the 1971–2000 climatology (circles, dashed line). Error bars indicate ±1 standard deviation. Watchtower Reports comprise the period 1823–1852 for dawn and 1806–1854 for midday and sunset.

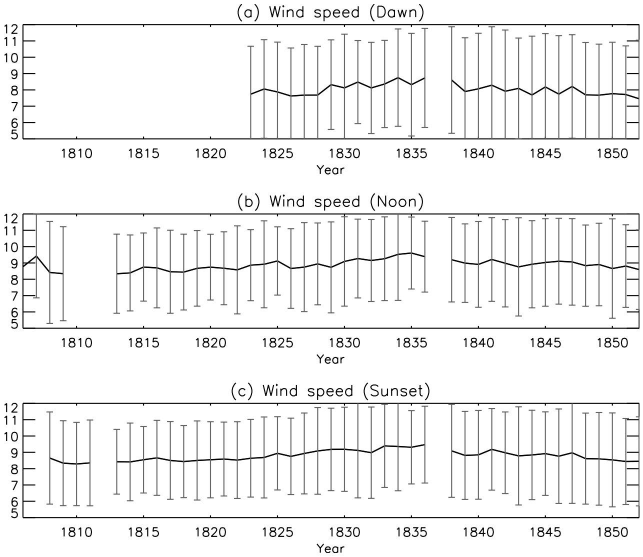

Figure 6. Annual average of the wind velocity (m s^{-1}) for the Watchtower Reports reconstruction. Error bars indicate ±1 standard deviation.

methodology (and subsequent translation) along the entire study period.

4. Summary and Discussion

[24] In this paper, a new data source for instrumental atmospheric pressure, temperature (1825–1852) and noninstrumental wind (1806–1852) is presented for the city of Cádiz. The temporal extension of the new instrumental series, while somewhat short, allows to compare the climatic record of an almost 28-year period in the 2nd quarter of the 19th century with those registered by the end of the 20th century. In addition, the wind records abstracted in this work have been used to compare historical and instrumental wind series.

[25] The instrumental historical watchtower pressure record follows closely the 1971–2000 seasonality, with a slightly lower SLP (about 1 hPa) in summer for the period 1825–1852 compared to 1971–2000. Our new SLP series does not match as well as expected with the equivalent CSF reconstruction although the CSF series tends to the Watchtower data when the corrections of *Vinther et al.* [2003] are taken in account. Watchtower SLP series are closer to present-day values but have a larger number of dubious records. In this regard, the uncertainties in the metadata associated with both historical pressure series make it difficult the interpretation of the differences that can be related to nondocumented changes in the location or type of barometer.

[26] In the case of temperature, the results are quite consistent when comparing both historical records with present-day values. Sunset temperatures between September and May, but especially from November to March, display a general warming of near 2°C. Average temperatures in summer are almost identical for the 1825–1852 and 1971–2000 periods. The significance of a winter warming for a city such as Cádiz is worth addressing. The Old City in Cádiz occupies a narrow peninsula (1.5 km at his widest point) which was already totally urbanized by the beginning of the 19th century. In addition, the city is totally surrounded by the sea, with the exception of a 500-m-wide terrain connecting it to the Spanish mainland. Despite the undeniable influence of the urbanization of nearby zones and the increasing use of heat-absorbent materials as asphalt or concrete along the 20th century, this particular geographic configuration would tend to minimize the urban thermal-island effect. The vast majority of the long instrumental climatic series are found in old European cities. Most of these have now become large urban areas, making it difficult to compare the first instrumental measures with observations of the current climate and largely masking urbanization effects. The combination of its geography and the availability of long instrumental series are extremely rare and make Cádiz a strategic location to monitor the effects of global warming in southern Europe. Despite the limitations of this study, specially the short length of the series, the tendency for lower amplitudes in the seasonal cycle in temperature, with milder winters and relatively unchanged summers now found in Cádiz, has been documented for a few instrumental and documentary European and Chinese series [*Jones et al.*, 2003]. If the annual asymmetry in the temperature increase is found to be general, this would imply an underestimation of global warming in proxies sensitive to summer conditions. More evidence in this sense is important to evaluate the performance of the paleoclimatic reconstructions on the basis of these kind of proxies [*Briffa et al.*, 2001].

[27] Because of their difficult quantification, early wind series have usually been of little use in historical climatology. However, the recent development of a methodology to estimate of the numerical equivalent of the wind data taken aboard sailing ships since 1750, has triggered the generation of a number of climatic reconstructions over areas yet unexplored by direct measures. *Jones and Salmon* [2005] developed a reconstruction of the NAO and the Southern Oscillation Index based solely on reconstructed logbook wind marine data, as did *Gallego et al.* [2005] for a new gridded SLP data set in the North Atlantic. While these reconstructions showed a consistent climatic signal, in general the anomalies in the variables deduced from the reconstructed wind components tended to be excessive compared with present-day values. *Gallego et al.* [2005] pointed out that this problem could be mostly due to the relatively low number of historical observations. This fact, evidently, plays a crucial role in the magnitude of the climatic reconstructions. In the case of Cádiz wind series, several factors can contribute to the large differences in the wind averages between historical and present-day anemometer records. First, the absence of metadata on the precise method involved in the wind observation at the Tavira tower originates an inherent uncertainty about the location of the wind records. Most probably, and because of the utility of these observations for the harbor activities, they were not referring to the wind at the same tower, but to the prevalent wind conditions inside the Cádiz Bay, as seen from the tower. On the contrary, present-day values are referred to a fixed point over the coastline inside the Cádiz Bay (see Figure 1). Second, assuming this hypothesis, the historical wind measurements could be reflecting the wind effects close to the sea surface, while present-day data are taken at

10 m above ground level. On the contrary, although less probable, if the historical wind records indicate the wind at the watchman location, at the top level of the Tavira Tower, they will be reflecting the wind at 33 m (although over the center of the city, a rougher terrain than the present-day measures over the coastline). Third, the translation of the watchtower reports has been made through the direct application of the CLIWOC dictionary [*CLIWOC Team*, 2003], which was originally derived exclusively from observations made at sea onboard of ships. This could introduce uncertainties difficult to estimate in the wind force, since both types of observations may not be directly comparable. Notwithstanding, the analysis of the historical wind series supports the climatic value both of the early wind measures and the recently developed translation methodology, as suggested by the almost perfect reproduction of the seasonal cycle of the wind force (Figure 5). However, the 2X factor in the wind force found in the Watchtower Reports compared to present-day data seems too large to be explained by the uncertainty in location alone. Wind records in the area surrounding Cádiz [*Instituto Nacional de Meteorología*, 2001] as well as the values of the NCEP/NCAR or ERA-40 reanalysis confirm that the wind speeds around 4 m s^{-1} found in the 1971–2000 series are representative not only of Cádiz, but of the entire area around the Strait of Gibraltar.

[28] Evaluating wind measures taken by human observers, who estimated the wind force by its effects over the sea, sails, flags, etc., with those registered by instruments is a challenging subject. Probably the main difference between instruments and human observers when "computing" the wind force is the sampling method. Wind force is one of the meteorological variables which can vary sharply with time. Anemometers average the wind force over a predefined period (10 min in the case of the current meteorological station in Cádiz), computing every change in wind force almost exactly (of course, depending on the raw sampling rate of the anemometer, typically in the order of the few seconds). On the other side, even an experimented human observer cannot pretend to achieve such precision. First, because it is virtually impossible for a watchman to sample and average wind force every few seconds and then into 10-min portions during a typical 8-hours shift and second, because of the larger integration times of the "tools" used to measure wind force, as its effect over the sea. Moreover it must be kept in mind that the ultimate purpose of wind measures aboard ships or in ports was not to compute the velocity of the wind, but to assure the safety of the ships. One cannot disregard the possibility that most historical wind series could be indicating the magnitude of the prevailing "wind gusts" rather than the average wind, as it is measured today by anemometers. Certainly this possibility does constitute neither an observation error nor a problem to the intended users of these measures, looking after the safety of the ships, but it should be taken into account by present-day users when trying to compare ancient and modern meteorological records. For the relevance for the future climatic reconstructions based on the historical wind series, it will be of the utmost importance to develop analogous studies from other sources to study the generality of this result.

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