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AURORAS OBSERVED IN PORTUGAL IN LATE 18TH CENTURY OBTAINED FROM PRINTED AND MANUSCRIPT METEOROLOGICAL OBSERVATIONS

JOSÉ M. VAQUERO
Departamento de Física, Escuela Politécnica, Universidad de Extremadura, Avda. de la Universidad s/n, 10071 Cáceres, Spain
(e-mail: jvaquero@unex.es)

and

RICARDO M. TRIGO
Centro de Geofísica da Universidade de Lisboa, Lisbon, Portugal; Departamento de Eng. Civil da Universidade Lusófona, Lisbon, Portugal

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Abstract. We present a new catalogue of observations of the aurora borealis at Lisbon, i.e., at low-latitudes, in the late 18th century by Jacob Prætorius and Henrique Schulze, two German artillery officers. Dates of 18 auroras compiled by Prætorius and Schulze are compared with those published in other catalogues for that period. The number of annual auroras observed by the two Germans is then compared with two indices of solar activity showing a very good level of consistency between all time series. Finally, we have assessed the number of auroras observed taking into consideration the phase of the lunar cycle and the geomagnetic latitude of Lisbon.

1. Introduction

A comprehensive report on the appearance of auroras at lower latitudes and during periods of relatively low solar activity has showed how neglected this phenomena has been by the scientific community (Silverman, 2003). However, some of these low latitude auroras can often be related with intense solar storms, events that with their associated flares and outstanding coronal mass ejection (CME) episodes can disturb spacecraft and power grid networks. Fortunately, recent developments in solar monitoring satellites (e.g., SOHO, Coriolis) have shown their ability to predict the timing for the arrival to Earth of solar flares and/or CMEs, a fact that can be of outmost importance to protect spacecraft, power grid networks and humans in space (Baker, 2000; Wu *et al.*, 2000). Therefore, the study of past aurora observations can help in determining confidence intervals on current studies of long-term cycles and trends of solar activity. Recent developments by the meteorological community have indicated the fingerprint of solar activity in our planet's climate (Friis-Christensen and Lassen, 1991). However, this issue remained highly controversial. Nevertheless, analyses performed over the last 5 years have shown unequivocally the impact of solar variability in stratospheric (Labitzke, 2005) and tropospheric climate patterns (Kodera, 2002; Baldwin and Dunkerton, 2005). The exact physical mechanisms responsible for this are not yet well understood, despite some early attempts to describe such mechanisms (Shibata and Kodera, 2005). Readers looking for substantial summaries are referred to the recent publications by Benestad (2003) and by Pap and Fox (2004). Solar activity is known to be modulated by the $\sim$11 year cycle of its own magnetic field and has been monitored, almost continuously, since Galileo's times through the associated sunspot cycle (Hoyt and Schatten, 1998) with constant improvements in what concerns old data (e.g., Vaquero, 2004). An indirect proxy of solar activity is given by the number of auroras borealis observed on Earth. Catalogues of auroras observed at a specific location are interesting tools for the study of solar–terrestrial physics. Historically, the first established catalogue of aurora was included in the work of Mairan (1733). These were followed by Kirch in 1735 (Schröder, 1996) and Frobesius (1739). Nevertheless, the best-known catalogue of the 19th century aurora was compiled by Fritz (1873) which included further information drawn from a great many sources. An extensive listing of southern hemisphere auroras can be found in Boller (1898). Of the 20th century catalogues, we would single out as of especial interest that written by Link (1962, 1964). In terms of auroras observed at latitudes lower than 55°N in the last millennium the work of reference is given by Křivský and Pejml (1988). Thanks to these compilations of auroral phenomena, it has been possible to study the variations of solar and auroral activities during past centuries (Silverman, 1992; Schröder, 1992, 1994a,b; Křivský, 1984). Therefore, catalogues of historical auroral observations have been used by several authors to obtain a better reconstruction of solar activity during the last millennium (Schove, 1979; Legrand *et al.*, 1991; Křivský, 1984) particularly during periods characterized by secular maxima (Willis and Stephenson, 2001) and minima (Schlamminger, 1990; Schröder, 1994a, b).

The main objectives of this paper are twofold: (1) to characterize the 18 auroras observed by Jacob Prætorius and Henrique Schulze between the years of 1781 and 1793 and; (2) to present a quality assessment of this new dataset, based on comparison with other auroras catalogues and the influence of the Moon's phase.

2. Data

Jacob Chrysostomo Prætorius (?–1798) was a German engineer who worked as an artillery officer under Count Lippe. Lippe and his officers were in charge of reorganizing the Portuguese Army during the Iberian Peninsula wars. His first period in Portugal took place between 1762 and 1764, he then returned to Germany until 1776. After this date he moved definitely to Portugal until his death in 1798 (Ferreira, 1944). With him came Henrique Schulze, another artillery officer who stayed in Portugal and performed observations of his own. Interestingly, the observational activities performed by these two gentlemen were primarily directed to climatic variables such as temperature, precipitation, pressure and humidity and to a lesser extent, cloudiness. Their observations for the period 1781–1785 and the years 1789 and 1793 were performed in Lisbon but were not aggregated into a single catalogue like the Spanish Catalogue of Rico Sinobas (Vaquero, Gallego, and García, 2003). Prætorius' observations were published separately, between 1782–1786, in four volumes of the Almanach de Lisboa (Prætorius, 1782, 1783, 1785, 1786). Furthermore, we have found two distinct manuscripts by Schulze and Prætorius containing further information on auroras for 1789 and 1793, respectively. The exact transcription of all above-mentioned observations is the following:

- "[1781] Observou-se alguma fraca luz de Aurora Boreal nos dias 24 Fever., 20 até 25 de Març., 17 de Abril, 13 e 25 de Maio, e 8 de Outub." [A faint auroral light was observed on 24th of Feb. and also between 20th and 25th of March, on the 17th of April, 13th and 25th of May and 8th of October] (Prætorius, 1782)
- "[1782] As duas Auroras Boreales rayantes de 5 de Maio e de 8 de Octubro naõ foraõ das maiores" [two auroras were observed on 5th of May and on 8th of October, however, those were not particularly large] (Prætorius, 1783)
- "[1783] Houve huma aurora boreal raiante no dia 27 de abril ás 10 horas, e varias luzentes por todo o anno até 11 vezes" [There was an aurora on 27th of April at 11 pm and many diffuse aurora episodes (11 times) throughout the year] (Prætorius, 1785)
- "[1784] Auroras boreales luzentes observaraõ-se 10 vezes pela maior parte em Fevereiro, accompanhadas sempre da luz Zodiacal" [Several aurora (10 times) were observed mostly during February accompanied by zodiacal light] (Prætorius, 1785)
- "[1785] observou-se huma só Aurora boreal luzente no dia 28 de Junho" [a single boreal aurora was observed on 28th of June] (Prætorius, 1786)
- "[1789] Aquellas tres Auroras Boreal annotadas luzentes com tudo naõ foraõ das majores somente a do mez de Janeiro representou-se mais visivel" [The three aurora observed this year were not particularly strong, except for the one in January] (Schulze, 1790)
- "[1793] A Aurora outro dia taõ frequente naõ apareceo" [those aurora, that used to be so frequent in the past, made no appearance this year] (Prætorius, 1794)

We must stress some notes on these words, particularly those raised by Prætorius. The comment on the relatively weak auroras observed in 1782 reveal that Prætorius had previously witnessed more impressive aurora, possibly in Germany, but almost certainly in Portugal because we know he had been producing meteorological observations since 1777 (Ferreira, 1944). Furthermore, from a reliability perspective

TABLE I
Auroras observed by Prætorius and Schulze in Lisbon, Portugal.

No.	Date	Julian day	Source	Notes
1	24 February 1781	2371612	(Prætorius, 1782)	faint light
2	**20 March 1781**	2371636	(Prætorius, 1782)	faint light
3	21 March 1781	2371637	(Prætorius, 1782)	faint light
4	22 March 1781	2371638	(Prætorius, 1782)	faint light
5	**23 March 1781**	2371639	(Prætorius, 1782)	faint light
6	24 March 1781	2371640	(Prætorius, 1782)	faint light
7	25 March 1781	2371641	(Prætorius, 1782)	faint light
8	17 April 1781	2371664	(Prætorius, 1782)	faint light
9	13 May 1781	2371690	(Prætorius, 1782)	faint light
10	25 May 1781	2371702	(Prætorius, 1782)	faint light
11	8 October 1781	2371838	(Prætorius, 1782)	faint light
12	**5 May 1782**	2372047	(Prætorius, 1783)	–
13	**8 October 1782**	2372203	(Prætorius, 1783)	–
14	**27 April 1783**	2372404	(Prætorius, 1785)	22 h
15	**28 June 1785**	2373197	(Prætorius, 1786)	–
16	**11 January 1789**	2374490	(Schulze, 1790)	6 h
17	**14 March 1789**	2374552	(Schulze, 1790)	3 h
18	**1 April 1789**	2374569	(Schulze, 1790)	5 h

Prætorius' aurora observation can fall into two distinct categories; those that have a date attached with the event and those that have not. Prætorius himself seems to de-emphasise the relevance of this second group of auroras. We believe that these observations should be disregarded, as these events probably correspond to other phenomena, such as noctilucent clouds, zodiacal light, and airglow; a confusion relatively frequent in those days. Thus, for the remainder of this work we have not considered auroras without a specific date. Table I shows the main characteristics of the 18 auroras considered, including the observation day, the corresponding Julian day, the document source and any further comment on that specific episode. Unfortunately, Prætorius and Schulze's aurora observations were relatively unsophisticated, not including relevant details such as azimuth and colour.

Prætorius and Schulze employ the ancient Portuguese terms "raiante" and "luzente" to designate the vast majority of auroras. In fact, besides specific columns for meteorological variables (e.g., temperature, precipitation) all manuscripts present two additional columns for the two described types of auroras. As with many other areas of knowledge it is particularly difficult to translate such terms into Modern English. Nevertheless, an attempt will be made: the word "raiante" refers to streams of light in the sky while the term "luzente" was employed to describe the more frequent, albeit fainter, diffusive type of auroras covering a wider area of the sky. We should stress that this dichotomy corresponds to the usual aurora classification scheme in the 18th century as described in the widely acknowledged treatise of Mairan (1733). In this seminal work, Mairan uses the French term "tranquilles" to describe those spread but generally faint auroras and the expression "grandes et completes" which corresponded to more spectacular (with rays and arcs) non-stationary type of auroras. Nowadays, these two types would correspond to the "diffuse" and "discrete" (Lynch and Livingston, 1995).

3. Discussion

We should raise some comments on the overall reliability of observations performed by both Prætorius and Schulze. In particular, it is necessary to assess how well this catalogue fits with other catalogues of aurora, and also with other time series related with solar activity. We will than evaluate the number of auroras observed as a function of the lunar phase. Finally, we present some comments on the dependence of our results on cloud cover and the geomagnetic latitude of Lisbon.

One of the most important catalogues of auroras observed at latitudes lower than 55° was compiled by Křivský and Pejml (1988, hereafter KP88), who have used a large number of original sources. In Table I we highlight (bold) observation dates made by Prætorius and Schulze that coincide with dates of observed auroras elsewhere in the world (KP88). However, most of the remaining non-coincident dates provided by Prætorius seem to be characterized by strong solar activity as these took place a few days before or after a previously identified aurora. In fact, Prætorius has observed aurora no. 1 on the 24th of February 1781 and KP88 have catalogued auroras in the 15th and 26th of that month. Moreover, auroras no. 2–7 were observed by Prætorius during the period 20th–25th of March, while KP88 include auroras observed on the 19th, 20th 23rd, 28th, and 29th of that very same month. This might correspond to a relatively unimportant mismatch of dates, as we believe that the expression used by Prætorius to describe the timing of March 1781 auroras is not very precise (check 1st transcription and translation in the list above). We are relatively confident that the German officer's intent with that sentence is to acknowledge the appearance of several consecutive auroras roughly between the 20th and 25th of March. Aurora no. 8 was observed on 17th of April 1781, and again KP88 provides observed events for the 14th and 15th of that month. Finally auroras no. 9 and 10 were observed by Prætorius on 13th and 15th of May 1781, and KP88 have registered auroras for the 14th, 16th, and 18th of that month.

It is necessary to contextualize the observations made by Prætorius and Schulze with other time series characteristic of solar activity for that period. Figure 1 shows the annual evolution of both the Wolf and Group sunspot numbers (solid lines). Moreover, besides the annual number of auroras observed by Prætorius and Schulze

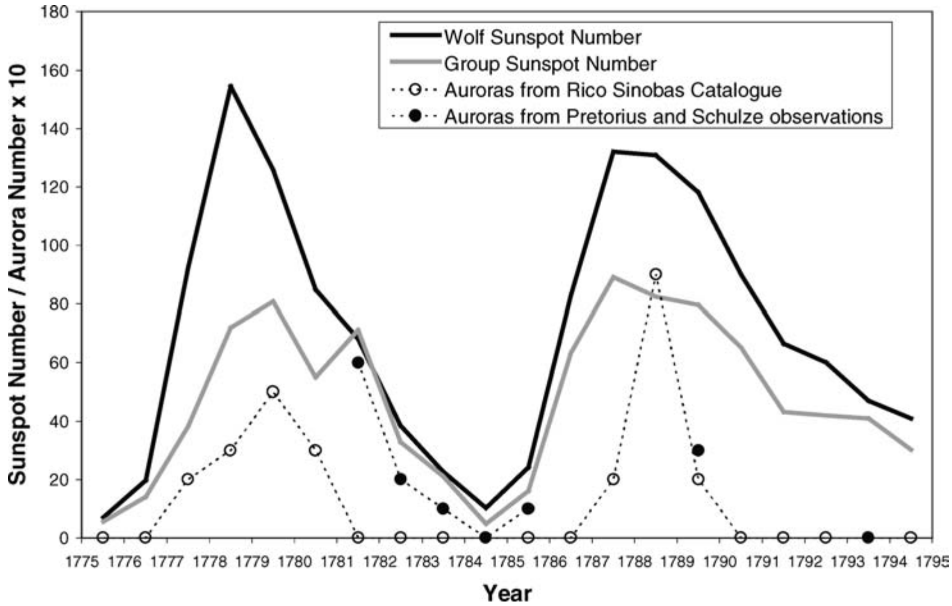

Figure 1. A comparison between the sunspot numbers and the number of auroras observed in Portugal from Prætorius and Schulze observations and in the Iberian Peninsula from Rico Sinobas' catalogue.

(black dots) we present the corresponding number of annual auroras recorded in nearby Spain by Rico Sinobas (Rico Sinobas, 1855; Vaquero, Gallego, and García, 2003). The consecutive auroral observations on 20–25 March 1781 probably refer to just one, albeit very intense, geomagnetic storm and not six distinct geomagnetic storms. Therefore, instead of eleven events we have considered only six independent auroral observations during the year 1781 in Figure 1. Overall, the number of auroras observed by the two German officers is in agreement with both sunspot indices and also with Rico Sinobas' data. Nevertheless, the number of auroras recorded by Prætorius and Schulze is consistently higher than those contained in Rico Sinobas' catalogue. In fact, as shown in Figure 1, Rico Sinobas' catalogue does not contain any aurora for the 1781–1785 period. These differences are most probably due to the distinct way both aurora time-series (Prætorius and Sinobas) were derived for those 5 years. In fact, while Sinobas collected published news of spectacular aurora observed by others, Prætorius was a keen observer, capable of detecting and recording fairly faint auroras that were not recognized by Sinobas' sources as particularly impressive, thus lacking the status to write an article.

In order to study the appearance of auroras according to the Moon's cycle we have considered the temporal distribution of auroras recorded by Prætorius and Schulze as a function of lunar phase (Figure 2). At the beginning of the lunar cycle (new moon) there is much less moonlight which favors the observation of most auroras, while the stronger light near full moon phase can obstruct the observation

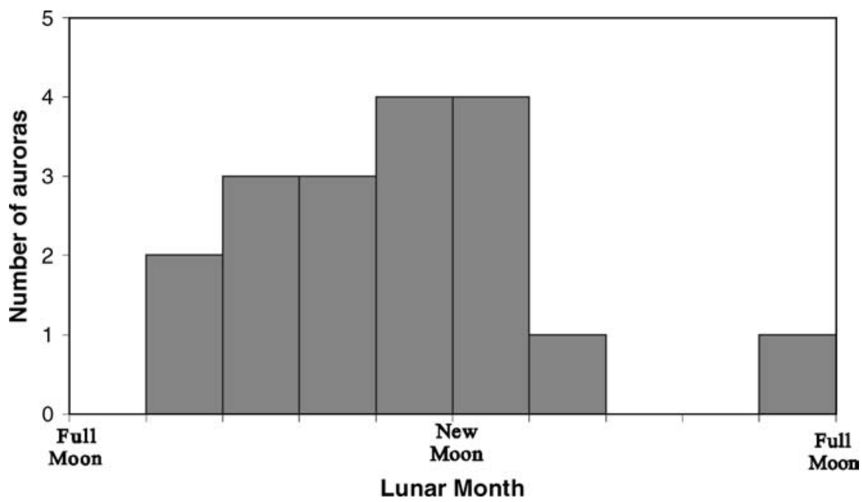

Figure 2. The temporal distribution of auroras recorded by Prætorius and Schulze as a function of lunar phase.

of weaker auroras (Vaquero, Gallego, and García, 2004). Thus, one can foresee that the peak of auroras would correspond to early evening observations made near the new moon phase. This empirical reasoning can be confirmed qualitatively in Figure 2, where the maximum of auroras does correspond to new moon and third quarter. However, a check of the observed values compared with a theoretically expected uniform distribution with respect to lunar phase using the Chi-squared test shows that this result is not statistically significant (probably as a consequence of the small number of observations available).

Interestingly, both observers compiled some cloud cover data for those years when auroras occurred. They classified days as belonging to one of the following classes; a) clear sky, b) partially clouded, and c) clouded. Both manuscripts contain some cloud cover for the corresponding years of 1789 and 1793 (Prætorius, 1794 and Schulze, 1790). Unfortunately, for the years 1781–1784 Prætorius has only published brief summaries on the cloud cover in the Almanach de Lisboa, (e.g., total number of days in each class between 1783 and 1785). Thus, only for the years of 1785, 1789 and 1793 do we have monthly frequencies for each class. As an example we show results for 1785 (Figure 3). However, the annual sum of days in each class for these 3 years is almost constant, a result that precludes a negligible dependence on the cloud cover of our results.

We have computed the temporal evolution of the geomagnetic latitude for Lisbon during the period 1600–2000 using the geomagnetic model gufm1 (Jackson, Jonkers, and Walker, 2000). Results are shown in Figure 4 and the most important features are the relatively constant maximum values observed during the entire 17th and early 18th century (about 50°), followed by a steady decrease throughout

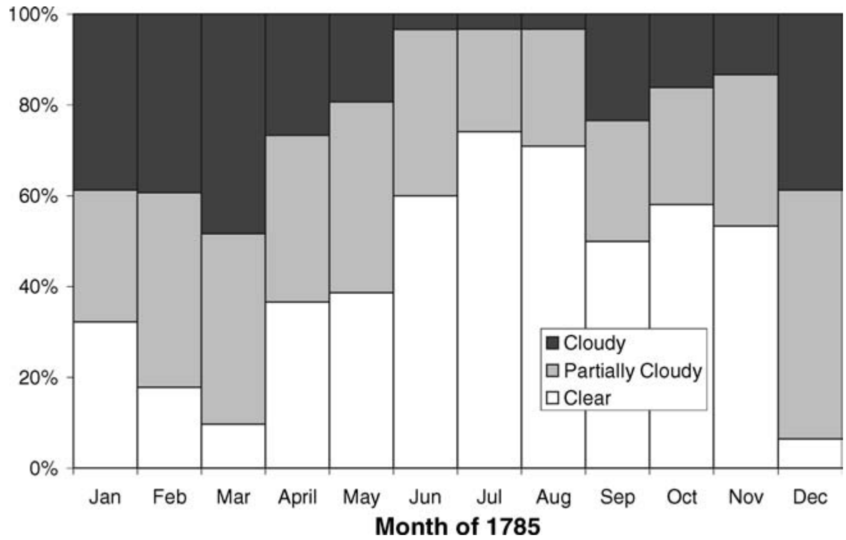

Figure 3. The evolution of cloudiness during the year 1785 in Lisbon using the Prætorius meteorological records.

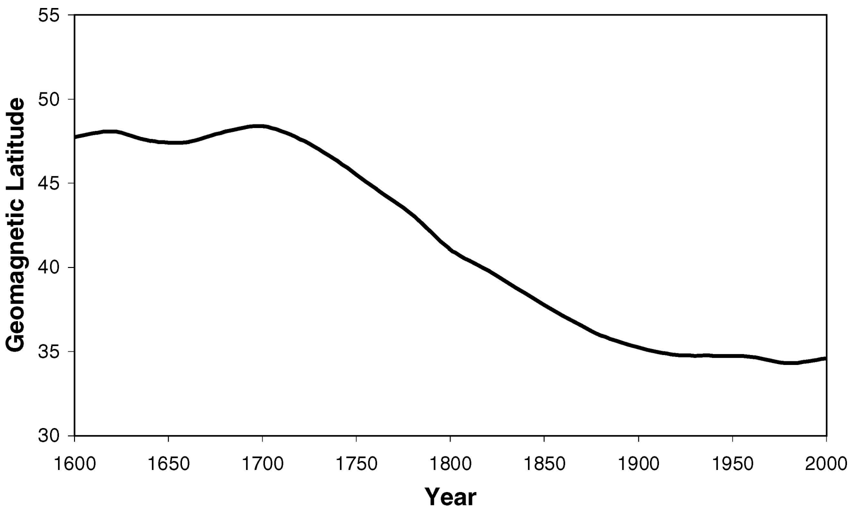

Figure 4. Evolution of the geomagnetic latitude of Lisbon.

the 18th and 19th centuries, until the nearly constant minimum values ($<35°$) observed during the 20th century. For the period under consideration in this work, the geomagnetic declination for Lisbon decreased from $43°.1$ (year 1780) to $41°.7$ (year 1794). It is worth noticing that Prætorius in 1794, when commenting on the absence of auroras in that year, stated that auroras used to be more common when he began observing them. Finally, from a long-term perspective, the significant decrease (about 15°) of the geomagnetic latitude for Lisbon between the early 18th century and 20th century may impact on the probability of observing auroras at these latitudes.

4. Conclusions

We have compiled a small catalogue of 18 auroras observed in Lisbon (Portugal), at the end of the 18th century, comprising the observations made by two German military engineers Jacob Crysostomo Prætorius and Henrique Schulze. All the information was retrieved from both printed and manuscript documents by these two authors and is summarised in Table I. To assess the reliability of these observations we compared them with other catalogues previously published, particularly if dates were compatible with other auroras observed at low latitudes. Furthermore, we compared the solar activity with the annual number of auroras observed (Figure 1). Overall, results confirm the quality of their observations, despite the relatively low number of observations available. The data recorded by Prætorius and Schulze shows no inconsistencies with respect to expected characteristics of distribution with respect to the phase of the Moon. The role played by cloudiness does not appear to be sufficiently relevant to impact on the annual average number of auroras observed, at least for those (few) years with available cloud cover data. Finally we computed the long-term variation of the geomagnetic latitude for Lisbon and show that the significant changes between the early 18th century and 20th century (about 15°) can influence the probability of observing auroras at these latitudes.

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