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Aurorae Observed at the Canary Islands

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Abstract Descriptions of eleven aurorae observed in the Canary Islands during the period 1770–2010 have been found in different documents. Most of them are coincident with periods of strong solar activity, with the geomagnetic latitude playing a minor role. Coronal mass ejections are the most probable solar source of these low-latitude events. The absence of low-latitude aurorae is verified in our sample during the Dalton Minimum and the first half of the 20th century.

Keywords: Solar Activity, Geomagnetic Storm, Aurora Borealis, Interplanetary Magnetic Field

1. Introduction

The visibility of aurorae is limited to ring-shaped regions around the geomagnetic poles, the auroral ovals, centred around 65 degrees of magnetic latitude (MLAT) in each hemisphere. Under the impact of a solar storm the auroral ovals undergo broadening, particularly on the night side. Low-latitude aurorae are very rare and are clearly associated with strong geomagnetic storms produced by solar coronal mass ejections. They are generally red and diffuse, resulting primarily from an enhancement of the 630.0 nm [OI] emission due to bombardment by soft electrons (<100 eV) precipitating from the plasmasphere (Tinsley, 1986). The typical altitude for a low-latitude aurora is 250–400 km (Roach *et al.*, 1960). They can be confused with distant fires or twilight due to their colour. The limits of such aurorae are usually 15 and 45 degrees of geomagnetic latitude.

In a previous paper (Vázquez *et al.*, 2006), we studied two historical aurorae observed at two low-latitude sites (Mexico City and Tenerife), establishing a correlation with several indices of solar activity and drifts of magnetic latitude at the two sites, in order to verify the adequacy of such terrestrial events to

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Table 1. List of the auroral events observed from the Canary Islands (C: confirmed, D: doubtful).

Date	Reference	Reliability
18 January 1770	Viera y Clavijo (1770)	C
27 October 1772	De La Guerra y Peña (2002)	D
22 September 1778	Madrid newspaper	C
14 November 1837	Tenerife newspaper	C
	J.A. Álvarez Rixo (1994)	C
17 November 1848	J.A. Álvarez Rixo (1994)	C
26 May 1854	Tenerife newspaper	D
29 August 1859	Ships	C
24 October 1870	J.A. Álvarez Rixo (1994)	C
4 February 1872	J.A. Álvarez Rixo (1994)	C
21 January 1957	Lanzarote and Gran Canaria newspapers	C
20 November 2003	Tenerife	C

track the long-term variation of solar activity in the past. For a monograph on historical aspects of solar activity see Vaquero and Vázquez (2009).

In this work we will concentrate our study on new reports found in Spanish publications, concentrating on the Canarian archipelago (28° N 16° W). These reports are listed in Table 1. For the purpose of illustration we also include a map of the archipelago (Figure 1).

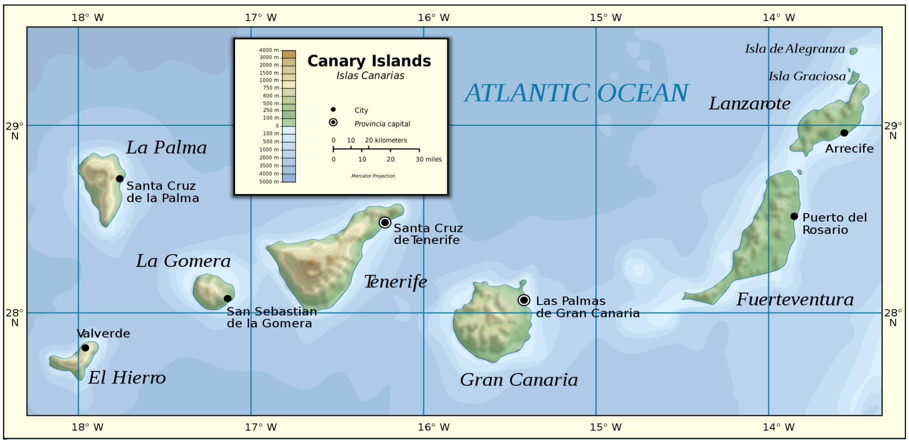

Figure 1. Map of the Canary Islands (adopted from http://en.wikipedia.org/wiki/File:Map_of_the_Canary_Islands.svg and modified by the authors).

After the Maunder Minimum, the works of Halley (1716) and Mairan (1733) marked the beginning of modern studies of aurorae. Krivský and Pejml (1988) and Krivský (1996) have compiled a catalogue[1] recording the aurorae visible in Europe in the period 1715–1850 at latitudes lower than 55 degrees. They assumed that nearly all the aurorae were recorded roughly after 1720, and that therefore no normalization factor needed to be applied (Figure 2). These records are compared with the catalogue of Angot (1897) for the period 1700–1890, also covering observations at latitudes lower than 55 degrees, and Fritz (1873) with no restrictions on latitude. Unfortunately, no such global catalogues exist for the 20th century.

The reduction in the number of aurorae observed during the Dalton Minimum is confirmed (Silverman, 1992; Broughton, 2002; Vaquero *et al.*, 2003). Two strong episodes of auroral activity are clearly seen around 1775 and 1850 (Figure 2) where the Canarian aurorae are concentrated (Table 1). Around the turn of the 20th century the level of solar activity decreases, and also the visual aurora monitoring. There is no recovery from this decrease until the start of the space age in 1957 (Siscoe, 1980; Legrand and Simon, 1987; Silverman, 1992).

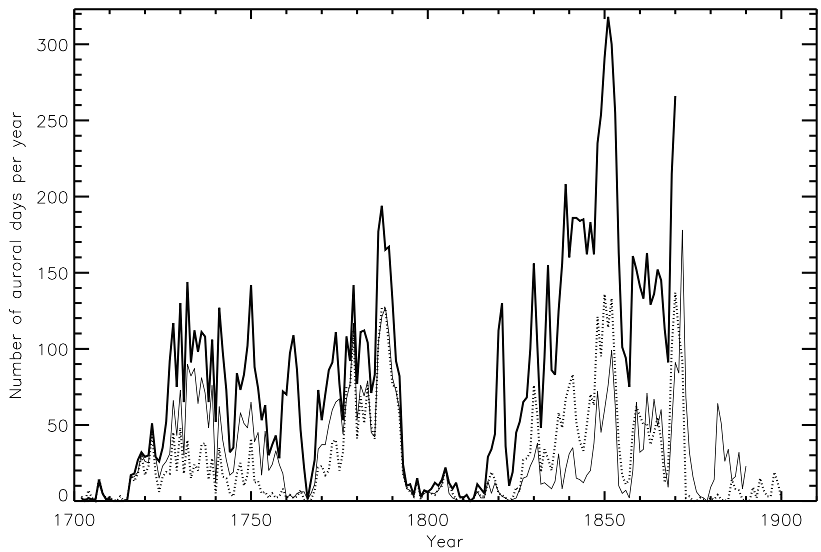

Figure 2. Yearly number of aurorae in the catalogs of (dotted) Krivský and Pejml (1988), updated by Krivský (1996), (thin solid line) Angot (1897) and (thick solid line) Fritz (1873).

Surprisingly, low-latitude aurorae have also been observed during periods of weak to moderate geomagnetic activity. Silverman (2003) has shown from US auroral data from 1880 to 1940 that some auroral phenomena occurred under conditions of quiet or moderate magnetic activity and at low latitudes. He used the term "sporadic aurora" for this type of auroral phenomenon. Vaquero *et al.* (2007) have studied one such event observed in 1845 in the Iberian Peninsula.

[1]Updated at the National Geophysical Data Centre.

Willis *et al.* (2007) compiled 42 Chinese and Japanese auroral observations during the period 1840–1911 and found that at least 29 out of the 42 observations (*i.e.* 69 %) occurred at times of weak to moderate geomagnetic activity.

There is also a semi-annual variation of auroral activity characterized by stronger and more frequent storms in spring/fall vs. summer/winter. The cause of this variation has long been a subject of discussion. During these seasons, Bz (perpendicular to the ecliptic component of the Interplanetary Magnetic Field, IMF) becomes large and negative (*i.e.*, the IMF tilts south) and it can partially cancel Earth's magnetic field at the point of contact, favouring the occurrence of an aurora.

2. Description of the Events

The first two events listed in Table 1 have already been described in some detail by Vázquez *et al.* (2006) and it is therefore not necessary to include this information here.

2.1. 22 September 1778

The newspaper *Gazeta de Madrid* on 9 February 1779 (page 99) reported the appearance of an aurora visible in the island of Lanzarote during the evening of 22 September 1778: "An aurora borealis of great brightness was observed in the capital of the island at 7:30 hours in the evening towards the north." This aurora is included in the UK records of Thomas Hughes (1771–1813) (Harrison, 2005) and in the catalogues of Angot (1897) and Fritz (1873), reporting observations in numerous European sites. New Moon in the northern hemisphere was on 20th September, so the conditions in this respect were perfect for the visibility of the atmospheric phenomena.

2.2. 14 November 1837

The Tenerife newspaper *El Atlante* reported on 15 November 1837: "Last night a phenomenon of great rarity at our latitude occurred. A beautiful aurora borealis, extending from the north to the northeast, was observed and lasted from nine o'clock in the evening until after eleven o'clock. Scattered white cloud in the foreground provided a pleasing contrast with the bright colour; however, the overall effect was slightly marred by the presence of moonlight compared to what it would have been on a dark night." Bernard (1837) described the first visual and geomagnetic observations of this event in New Haven and Great Britain.

2.3. J.A. Álvarez Rixo and Four Aurorae: 1837, 1848, 1870 and 1872

José Agustín Álvarez Rixo (1796–1883) held administrative positions in the city of Puerto de la Cruz (including three short periods as mayor), but he also dedicated time to the history of the Canary Islands. In his *Anales del Puerto de la Cruz: 1701–1872*, he described four aurorae. The first of these (14 November

1837) is the one described in the previous subsection: "At about ten o'clock in the evening a fiery red cloud was seen over the sea towards the north–northwest, which extended towards the east and west. It remained visible for about an hour and then began to disperse. The moon was bright and beginning to wane, and the air was clear. ... The common people were alarmed and called on God and the saints, etc. But this phenomenon was in fact an aurora borealis, almost never seen from here."

This aurora was also observed in Tenerife by the painter Alfred Diston (1793–1861). Based on this last report, Loomis (1860) commented that this aurora was visible in Tenerife "for the first time in the memory of man" (see Table 5.9 of Shea and Smart, 2006). This statement is clearly untrue.

The aurora of 17 November 1848 was commented on briefly by Álvarez Rixo: "At about nine o'clock in the evening a bright aurora borealis was seen towards the northeast. It lasted several hours and uneducated people began to clamour and pray, as is their wont before all that they do not understand." This aurora was also observed by A. Lang, Governor of Saint Croix Island (17°44'32" North, now a part of the Virgin Islands), who commented that the red glare ascended high above the hills, leading several persons to believe that a tremendous fire had occurred (Lang, 1849). One day before, a large sunspot on the solar disk was visible to the naked eye (Wittmann and Xu, 1997). This aurora was also observed in the Iberian Peninsula and included in the catalogue of Rico Sinobas (Vaquero *et al.*, 2003).

Álvarez Rixo commented, again ironically, about the reaction of the people on the occasion of the 24 October 1870 aurora: "Between eight and nine o'clock in the evening an aurora borealis appeared in the NE. The common people interpreted it as a harbinger of war." The whole auroral event was studied in detail by Vaquero *et al.* (2008). Some days later, October 28, the Tenerife newspaper *El Pueblo* reported: "In the night of last Monday [Oct 24] the aurora borealis appeared in the north, and was repeated with less intensity on Tuesday night."

Finally, Álvarez Rixo reported briefly the sighting of another aurora on 4 February 1872: "In the first hours of the night an aurora borealis was observed in the north-northwest direction. After midnight, rainfall commenced in the same direction with strong wind and thunder storms." The associated geomagnetic storm was included by Jones (1955) and Vallance Jones (1992) in his list of outstanding solar events. Greenwood (1872) and Chapman (1957) commented that the event was seen in low-latitude sites such as the Caribbean, Egypt and India. In the southern hemisphere, Stone (1872) described observations in South Africa, reaching low-latitude sites such as Bloemfontein (29° 8'). Wedderburn (1872) reported observations in the south-east of France, starting around sunset and showing a combination of green and red colors. Recently, Silverman (2008) reported observations of this event as low as 20° geomagnetic latitude.

Other reports in Álvarez Rixo's book mentioned several atmospheric phenomena: "from midnight until near dawn notable exhalations were seen toward the east" (14 November 1868), "as early in the night a great exhalation was seen from east to northwest" (6 June 1871). However, no aurorae were reported on these dates at other sites, the solar activity on these days was rather low and

Table 2. Observations at sea during the 1859 event in positions close to the Canary Islands.

Date	Time	Location	MLAT	Reference
28/29 August		26° N 27° W	34° N	Kimball (1960)
	3h15m- 4h15m	26° N 27° W	34°	Kimball (1960)
	11h 15mp.m-00h0m	25° 45' N 27° 4' W		Loomis (1861)
2 September	3h 30m a.m-dawn	27° 20' N 34° 34' W		Wilson (2006)

their description is very vague. The cited phenomenon was probably a great meteor.

2.4. 26 May 1854

A journalist of the Tenerife newspaper *Eco del Comercio* describes the following observation at the southern site of Arona at 7 hours in the evening of 26 May 1854: "A great brightness, like that of a great fire, was seen over the Roque district of Adeje, located to the west of that town. Many people, not understanding the effects of this meteor, were seized with anxiety ... The light persisted for half an hour, until, with a great noise over the mountains, it disappeared towards the peak. An old man of the town said that the phenomenon was an aurora borealis." The description is too vague, and also may be related to other atmospheric phenomena. An aurora is included for this day in the catalogue of Fritz (1873) but not in that of Krivský and Pejml (1988) and Krivský (1996).

2.5. 1 September 1859

The solar storms of August/September 1859 (the Carrington event) were probably the largest solar event ever recorded. In a set of eight papers published in the *American Journal of Science*, E. Loomis collected the direct observations of the events (collected by Shea and Smart, 2006). Later, Chapman (1957) and Kimball (1960) studied the spatial distribution of the observations. Tsurutani *et al.* (2003) studied this event from the geomagnetic record obtained at the Colaba Observatory (near Bombay, India). Cliver and Svalgaard (2004) mentioned six well documented aurorae within 30° of the geomagnetic equator. In a special issue of *Advances in Space Research*, several papers have updated our knowledge of this event (*e.g.*, Green and Boardsen, 2006; Wilson, 2006). Recently, Ribeiro *et al.* (2010) located another geomagnetic record of this event from Guatemala Observatory.

Table 2 summarizes the observations made at mid-latitudes in the Atlantic Ocean. These positions are only slightly to the west of the Canary Islands (see map of Figure 1). The moonlight was very faint with New Moon on 28th August. However, we have not been able to find any auroral reports of such events in the Canaries.

2.6. 21 January 1957

This aurora was visible in central and southern Europe. Lisak and Marki (1998) describe two reports of such events in Croatia, remarking that the light was dark red being darker near the horizon and disappearing towards zenith. Groubé *et al.* (1957) reported the visibility of this aurora in different cities of Morocco, noting the red color. The maximum D_{st} of the corresponding geomagnetic storm was 250 nT (Archives of the National Geophysical Data Center).

On 23 January the Las Palmas newspaper *Falange* reported from Arrecife (Lanzarote) this description: An extended bright red cloud, emitting brilliant flashes, was observed from rooftops last night by many in the neighbourhood of Puerto Naos. It was also seen by passengers on buses and several farmers, some of whom fled terrified because the phenomenon occurred with an overcast sky accompanied by thunder and lightning, all of which combined to produce an impressive spectacle. After fifteen minutes, the sky was covered with an extensive black cloud, which produced a spectacular colour contrast.". The Lanzarote newspaper *Antena* confirmed some days later (29 January) that this event was visible on 21 January from Puerto Naos in Arrecife and from other villages on the island: "It appeared in the form of a strange, intensely red cloud and lasted for about 15 minutes. The phenomenon coincided with outbursts of thunder and lightning, giving rise to an impressive spectacle."

2.7. 20 November 2003

Within the scope of modern solar observations, we have primary evidence based on a set of five photographs taken by Mr. Graham Parkin on the summits of Tenerife, close to Mt Teide (3717 m a.s.l). Figure 3 shows one of these. The Aurora started at around 21h UT and lasted until 22h 10m.

This aurora is associated with the largest geomagnetic storm, one of the greatest events in the period 1957–2003 (Karavaev *et al.*, 2009). It was produced by a halo CME, originated in NOAA AR 10501 on 18 November associated with a relatively weak M-class flare. What made this event so special was not the source region but the high IMF and its strong southward component (Gopalswamy *et al.*, 2005; Srivastava *et al.*, 2009), giving rise to a strong reconnection of the magnetic cloud with the geomagnetic field. The duration of the solar wind–magnetopshere interaction was surprisingly long: 13 hours (Srivistava, 2005). Table 3 summarizes the main characteristic of the event. During the magnetic cloud passage, large red/blue ratios were seen, suggesting the presence of a type-A red aurora originated by an enhancement of low-energy electron precipitation (Hecht *et al.*, 2008). Kumar *et al.* (2010) describe the associated flares and the topology of the magnetic field during this event. Curiously, no reports of this aurora have been found in the Canary Islands press, but it was observed in various places in the Iberian Peninsula.

In the following we will consider different parameters that might help explain the temporal distribution of the aurorae observed in the Canaries.

Figure 3. Auroral glow above the sumit of Mt Teide (Tenerife) on the night of 20 November 2003. Exposure time 30 s with a Nikon FM2, 35mm lens, camera on Fuji Superior 800 ASA. Courtesy: Graham Parkin (UK).

Table 3. Physical parameters of the geomagnetic storm (20 November 2003) and its solar source. See the text for references.

CME	
Time (UT)	18 November 08:50:05
Source location	S02E18
Source area	370 $10^{-6} A_{\odot}$
Linear speed	1660 km s^{-1}
Kinetic energy	(1.65-6.6) $\times$ 10^{32} erg
Interplanetary magnetic field	
Strength	52 nT
B_z	-56 nT
Geomagnetic storm	
Time (UT)	08:00 (20 Nov) – 08:00 (21 Nov)
$K_{\rm p}$ (max)	8.7
$D_{\rm st}$	- 472 nT

3. The Level of Magnetic Activity

We can divide the effects of the solar activity on our planet into two different agents, depending on the topology of the magnetic field of solar atmosphere.

a) *Closed Regions*: The magnetic flux of the active regions is characterized by magnetic configurations with closed field lines dominating the variations in the total irradiance and emission in the high energy range of the solar spectrum (ultraviolet and X-rays). For historical reasons it is usually characterized by the sunspot number. Coronal mass ejections (CMEs) are transient phenomena linked to large-scale reorganizations of the magnetic field and consist of huge emissions of solar particles that in some cases impact the Earth's environment. The CME rate follows the solar cycle (Webb and Howard, 1994; Robbrecht *et al.*, 2009) and the Gnevyshev gap (Gnevyshev, 1967).

b) *Open regions*: Large-scale magnetic regions have field lines open toward the interplanetary medium. They are the main source of a continuous outward flow of charged particles (protons, electrons and helium nuclei) known as the solar wind. Long-lived coronal holes are the sources of high speed solar wind and are related to recurrent geomagnetic activity. They occur more frequently in the declining phase of the sunspot cycle.

The solar magnetic field of the open regions (OMFs) is frozen into this wind, thereby configuring the interplanetary magnetic field (IMF), which produces the heliosphere that fills practically the whole Solar System. Lockwood *et al.* (1999) and Lockwood (2003) have derived the intensity of the interplanetary magnetic field from the *aa* geomagnetic index, a record that extends back to 1868. They found that the average strength of the solar magnetic field has doubled in the last 100 years. Usoskin *et al.* (2002) carried out simulations of the variations of the OMF with a model based on the emergence and decay rates of active regions (Solanki *et al.*, 2002) that fit reasonably well with other proxies of solar activity, such as the ^{10}Be records in ice cores.

The numbers of aurorae are clearly related to the level of solar activity. Records show the well-known Spörer, Maunder, Dalton and 1901–1913 minima including a hitherto unrecognized long-term minimum around 1765 (Silverman, 1992, 1995). A double peak in the geomagnetic records has been observed with the two maxima: a) shortly before the sunspot maximum and produced by transient events (Gonzalez *et al.*, 2002) and b) two years after the maximum mainly produced by recurrent events (Tsuratani *et al.*, 2006). Geomagnetic activity is higher in the second half of the even-numbered cycles and in the first half of the odd-numbered cycles, giving rise to a 22 yr variability (Chernosky, 1966: Vennerstrøn and Friis-Christensen, 1996). For a discussion of the geoeffectiveness of the different solar sources of geomagnetic disturbances see Georgieva *et al.* (2006).

Figure 4 plots the dates of the Canarian aurorae against the variation of sunspot number (closed regions) and open magnetic field. We find that the aurorae in our sample coincide quite well with the maximum of the corresponding solar cycle.

4. The Geomagnetic Latitude

We have computed the time evolution of the geomagnetic latitude for Lanzarote and Tenerife during the period 1600–2000. We have obtained the magnetic inclination (I) from the global geomagnetic model *gufm1* (Jackson *et al.*, 2000), useful for relatively short periods of time. The geomagnetic latitude, ϕ, was computed from the expression $\tan\phi = (\tan I)/2$ assuming a dipolar configuration for the

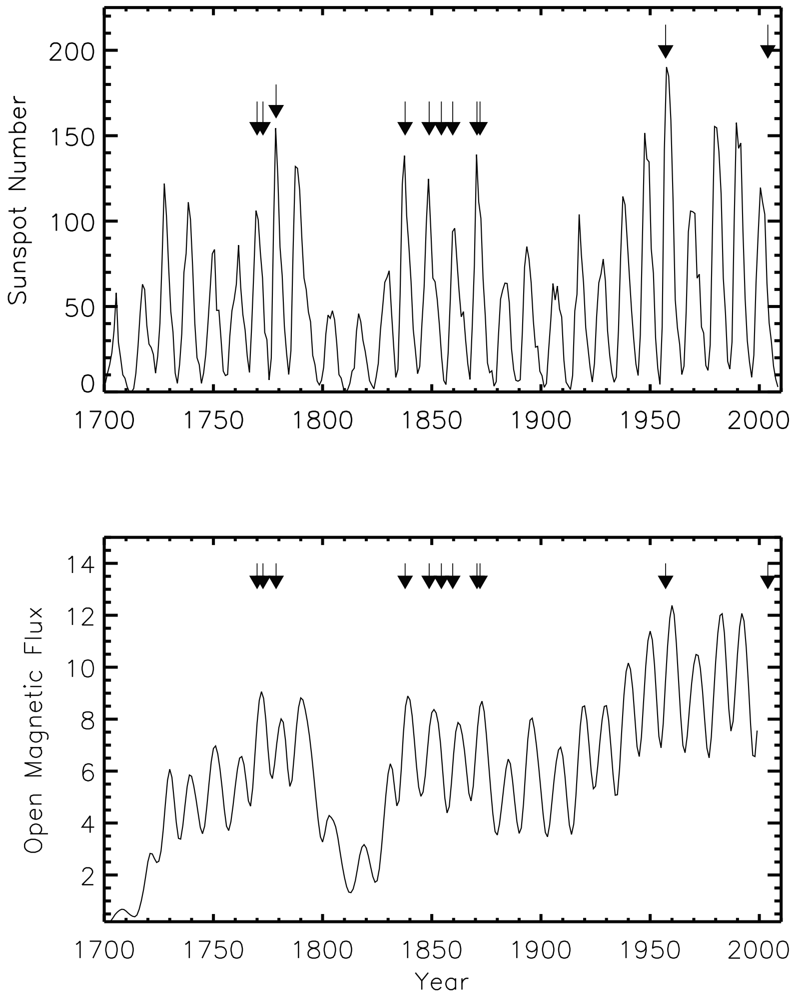

Figure 4. Variation of solar activity in the period 1700–2005 expressed by: a) closed magnetic field (CMF), indicated by the sunspot number and b) open magnetic flux (data courtesy of M. Schüssler, MPIfA, Germany), calculated by Usoskin *et al.* (2002). Arrows indicate the dates of aurorae borealis observed in the Canary Islands.

geomagnetic field. The results are shown in Figure 5. Both sites currently have very low geomagnetic latitude and are therefore not very promising for observing aurorae. However, the geomagnetic latitudes of the islands attained a peak value around 1750, reaching nearly 44°, but have been less than 30° since 1900. This trend is in agreement with the auroral observations, which are concentrated in the high geolatitude period, but it is not a limiting factor. In fact, we have two strong aurorae in the 20th century, where the values of MLAT are relatively low.

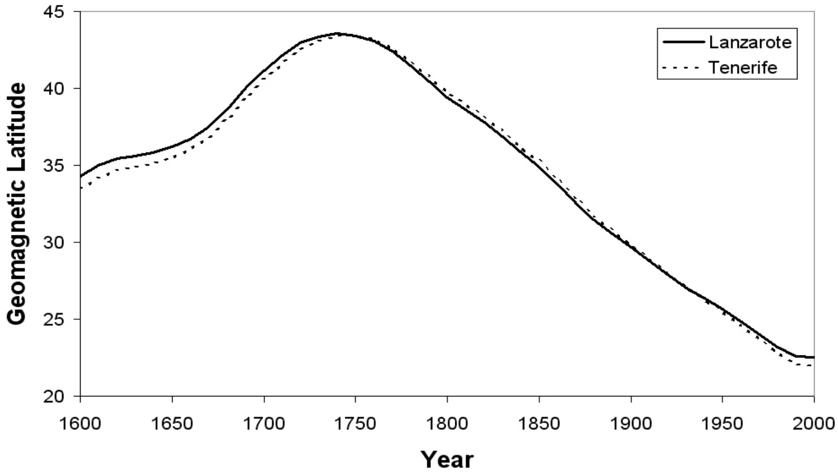

Figure 5. Variation of the magnetic latitude of Tenerife and Lanzarote for the period 1600–2000.

5. The Geomagnetic Index

Several indices represent the response of the geomagnetic field to a solar storm. For historical purposes the *aa* index must be used here. Figure 6 plots the temporal variation of this parameter for the period 1844–2000, where some of our aurorae are indicated. Based on this index, Lockwood *et al.* (1999) established that the heliospheric magnetic field doubled during the last century, a claim verified later by models of the solar magnetic field (Solanki *et al.*, 2002) and cosmogenic isotopes (Solanki *et al.*, 2004).

Silverman (2006) established an empirical relation between the magnetic latitude of the maximum equatorward extension of visual aurorae, ϕ, as a function of the maximum half-daily *aa* for the event:

$$\phi = 55.86 - 0.056\, aa.$$

Taking this relation just as a guide, we could have an explanation of the lack of observations after 1872. The biggest event (aa=381), 11 May 2003, should also be visible northward of 34 degrees of magnetic latitude. However, we should remember that the *aa* index is not a perfect proxy of auroral activity produced by transient CME events (Richardson *et al.*, 2000, 2001).

6. Interplanetary Magnetic Field

The interplanetary magnetic field adopts the shape of an Archimedes spiral and is related to the OMF. Its topology is an essential ingredient to understanding the best conditions for interactions with the Earth's magnetosphere after a solar storm to produce an auroral event.

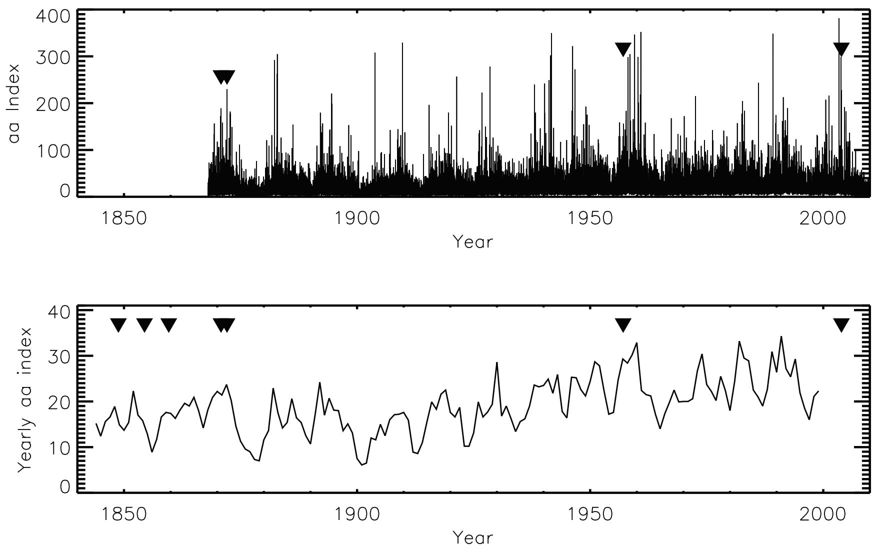

Figure 6. Variation of the aa geomagnetic index for the period 1870–2010 (top) and Helsinki yearly aa-index (bottom) from Nevanlinna and Kataja (1993). Arrows indicate the dates of the more recent aurorae in our sample.

Cosmogenic isotopes, such as ^{14}C and ^{10}Be are adequate proxies of the interplanetary magnetic field. From these records the long-term IMF has been inferred. For our period of study, different reconstructions (McCracken, 2007; Rouillard *et al.*, 2007; Steinhilber *et al.*, 2010) that are based on the method of Caballero-López *et al.* (2004) show similar trends since 1870 with a clear minimum around 1900. However, Svalgaard and Cliver (2005) show high values around 1900, based only on geomagnetic indices.

Recently, Svaalgaard and Cliver (2010) have reevaluated the heliospheric magnetic field (Figure 7). We see clearly a decrease in the values in the period 1880–1950, just where we have no auroral observations in the Canaries. The 1854 and 2003 events are not coincident with high values of the IMF.

7. Conclusions

A historical search for aurora sightings in the Canary Islands has been carried out using different documentary sources. Clearly, the number of aurorae recorded in this work is a lower limit of those visible from the Canary Islands, especially for the period 1715–1870. Cloudy skies or the lack of attention of the inhabitants or press media to such phenomena clearly limit their detection.

The auroral power depends mainly on the following factors: a) the solar wind speed, larger for strong storms, b) the interplanetry magnetic field, stronger for periods of high magnetic activity (see Figure 7), and c) the sine of the polar angle of the IMF, that is 0° for a northward field and 180° for a southward field.

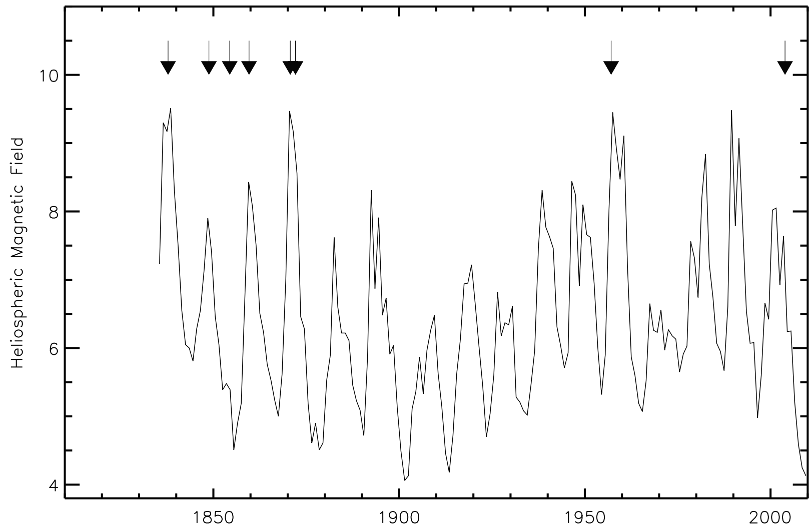

Figure 7. Yearly variation of the Heliospheric Magnetic Field (in nT) for the period 1836–2009 (Svaalgard and Cliver, 2010).

We were able to pick up observing reports of aurorae in all the maxima of activity cycles in the period 1770–1872. This seems to identify CMEs as the main sorce of auroral events in our low-latitude sample. A lack of aurorae is found during the Dalton Minimum, confirming previous studies. Only one sporadic aurora, an event close to an activity minimum, has been recorded (1854), although its evidence is quite marginal and needs to be confirmed from other sources. The peculiarities of the strong southward turning of the IMF before the geomagnetic storm explains the 2003 event Unfortunately, no similar data exist for the other events.

It is a little puzzling that only two auroral reports has been found after 1872. Apart from solar and interplanetary causes, we should also consider other possible effects. The increasing light pollution in cities could play a role, but we have checked the observing logs of the Meteorological Observatory at Izaña (Tenerife), a non-polluted site, and no mention of aurorae has been found. The aforementioned decrease in auroral monitoring is a fact in American and European sources, but not to be applied to the Canaries, where the auroral observations were not a consequence of any systematic scientific program.

We could tentatively attribute this lack of observations to the decrease of the geomagnetic latitude. However it is also clear that auroral events have been reported at lower geomagnetic latitudes during the 20th and 21st centuries and the trend in this parameter in the Canaries should be compensated by the appearance of strong solar storms (Chapman, 1957; Vallance Jones, 1992).

The combination of different auroral catalogues clearly indicates a strong decline in auroral activity during the Dalton Minimum and after 1880, two minima in the 80-yr Gleissberg cycle (Garcia and Mouradian, 1998). Not much solar information is available for the first episode, but more exists for the second. In this context it is worth commenting that some studies indicate a pronounced change in solar rotation around 1900 (Balthasar *et al.*, 1986) that surely also affected the heliosphere (Echer *et al.*, 2004; Outtara *et al.*, 2009) and therefore the number of auroral events (see Silverman and Blanchard, 1983). Echer *et al.* (2004) suggest that OMF structures have increased their activity relative to CMF structures during the last 130 years. Reconstruction of the OMF by Rouillard *et al.* (2007) concludes that from 1903 to 1956 the OMF increased by about 87%, to be compared with the 130%, 80%, and 25% provided by Lockwood *et al.* (1999), Steinhilber *et al.* (2010) and Silverman and Cliver (2005), respectively. Mursula *et al.* (2004) find that the geomagnetic increase in the *aa* index is higher at high-latitude stations and lower in mid- and low stations, indicating that only solar wind disturbances (open regions) leading to moderate geomagnetic activity, have increased during this period.

In any case, the non-visibility of some auroral events in the 20th century from the Canaries is worth discussing in more detail. Silverman (1995) proposed that the lowest credible magnetic latitude for the 25 September 1909 auroral event was between 30° and 36° The Canary Islands were within this threshold. Silverman and Cliver (2001) established a lower latitude limit of 30–35° for the storm of 14/15 May 1921, but the geographic longitudes where the aurora was visible were far from the Canaries.

The aurora occurring on the night of 25/26 January 1938 was clearly visible from the Iberian Peninsula, the Madeira archipielago and North Africa (Algeria and Morocco). It happened in the middle of the Spanish Civil War and its description is found in several newspapers of the Iberian Peninsula, which reported that red lights and geomagnetic disturbances were recorded at the Observatorio of San Fernando (Cádiz). In the North Atlantic, the lowest latitudes at which ships reported the aurora were from the *Malvina* (MLAT 35.8) and the *King Robert* (MLAT 35.3) (see Silverman, 2006). The newspapers of the Canary Islands reported the event over several days but without reporting any observation in the archipielago.

Low-latitude aurorae are mainly produced by strong CMEs taking place around the maxima of the solar cycle. However, the geoeffectivity of such solar transitory events depends critically on the level of the IMF and its position with respect to the Earth's magnetosphere. Further historical research is necessary to complete, as fully as possible, this preliminary catalogue of aurorae recorded in the Canary Islands and extend it to other low-latitude sites. These historical auroral records will serve as a proxy for strong solar storms that have occurred in the past, thereby facilitating further studies of the long-term variability of the heliosphere.

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