Dear Editor,

The authors want to thank the reviewers for their work on the submitted paper.

In the following, specific answers to the comments are reported and all changes in the new revised manuscript are highlighted in yellow.

Reviewer #1:

R1: I have carefully read the paper titled "An Early Low Latitude Aurora Observed by Rozier (Beziers, 1780)". The authors present a suspected aurora observed by Francois Rozier on 15 August 1780 in Beauséjour, close to Beziers (at MLAT= 50.18 N, according to the authors). It should be noted that the observation was made under adverse weather conditions (presence of a lightning storm). In section 4, the authors indicates that at the same time an aurora was also observed at Ratisbon (Germany, 49 N), 5.5 further north than Beziers, and recorded in Angot's catalogue (Angot, 1897). If this article is selected for publication, I suggest some revisions to the manuscript and other small suggestions before it can be published in ANGEO.

A: Many thanks for your detailed review. We have taken into account all your suggestions and the manuscript has improved a lot.

R1: **1 Background and Introduction** Line 20: For the physical mechanism of the aurora origin, (Vazquez et al. 2014) is not the appropriate reference (see e.g., Brekke, 2013, Physics of the Upper Polar Atmosphere, 2nd edn. Springer, Heidelberg).

A: We agree with the referee, We have deleted the cite of Vazquez et al. 2014 and included two more appropriate cites i.e. Brekke 2013 and Gonzalez et al., 1994.

Brekke, A.: Physics of the Upper Polar Atmosphere, 2nd Ed., (Springer) 2013.

Gonzalez, W. D., Joselyn, J. A, Kamide, Y., Kroehl, H. W., Rosoker, G., Tsuruani ,B. T. and Vasyliuna, V. M.: What is a geomagnetic storm?, J. Geophys. Res., 99, 5771-5792, doi.org/10.1029/93JA02867, 1994.

R1: Lines 25-26: The three articles cited relate to the Carrington event. It is interesting to point out other exceptional events, such as that of 1921 (Silverman, S.M., Cliver, E.W.: 2001, J. Atmos. Solar-Terr. Phys. 63, 523), as well as that which occurred in 1770 (Hayakawa, H., et al.: 2017, Astrophys. J. Lett. 850, L31).

A: We have included the events proposed by the referee and other important and well-studied events. Moreover we have updated some references of the Carrigton storm in accordance with referee 2. "This was the case of well studied extreme space weather events as those occurred on September 1770 (Hayakawa et al. 2017a); the Carrington event in August/September 1859 (Green and Boardsen, 2006; Green et al., 2006; Humble 2006; Tsurutani et al., 2003; Cliver and Dietrich, 2013; Hayakawa et al., 2019a); the storm on 1872 February (Hayakawa et al. 2018; Silverman, 2008); the extreme event on September 1909 (Hayakawa et al., 2019b); May 1921 (Hapgood, 2019; Silverman and Cliver, 2001; Love et al., 2019) or March 1989 (Allen et al., 1989) resulting in extreme magnetic disturbances and auroral displays at very low latitudes ."

Hayakawa H., Tamazawa H., Ebihara Y., Miyahara H., Kawamura A. D., Aoyama T. and Isobe H.: Records of sunspots and aurora candidates in the Chinese official histories of the Yuán and Míng dynasties during 1261–1644, Publ. Astron. Soc. Jpn 69, 65, doi: 10.1093/pasj/psx045, 2017a.

Green, J. L. and Boardsen, S.A.: Duration and extent of the great auroral storm of 1859, Adv. Space Res. 38, 130–135, 10.1016/j.asr.2005.08.054, 2006.

Green, J.L., Boardsen, S. A, Odenwald, S., Humble, J. and Pazamickas, K.A.: Eyewitness reports of the great auroral storm of 1859, Adv.Space Res. 38-2, 145-154, doi.org/10.1016/j.asr.2005.12.021, 2006.

Humble, J.: The solar events of August/September 1859 – Surviving Australian observations, Adv. Space Res. 38, 155–158, 10.1016/j.asr.2005.08.053, 2006.

Tsurutani B. T., Gonzalez W. D., Lakhina G. S., Alex S. (2003) The extreme magnetic storm of 1–2 September 1859, J. Geophys. Res., 108, 1268, doi:10.1029/2002JA009504.

Cliver, E. W. and Dietrich, W. F.: The 1859 space weather event revisited: limits of extreme activity, J. Space Weather Space Clim. 3, A31, doi: 10.1051/swsc/2013053, 2013.

Hayakawa, H., Ebihara, Y., Willis, D.M., Toriumi, S., Iju, T., Hattori, K., Wild, M. N., Oliveira, D. M., Ermolli, I., Ribeiro, J. R., Correia, A.P., Ribeiro, A. I. and Knipp, D. J: Temporal and Spatial Evolutions of a Large Sunspot Group and Great Auroral Storms Around the Carrington Event in 1859, Avd. Space Res, 17, 1553–1569. https://doi.org/10.1029/ 2019SW002269, 2019a.

Hayakawa, H., Ebihara, Y., Cliver, E. W., Hattori, K., Toriumi, S., Love, J. J., Umemura, N., Namekata, K., Sakaue, T., Takahashi, T., and Shibata, K.: The extreme space weather event in September 1909. Monthly Notices of the Royal Astronomical Society, 484, 3, 4083-4099. DOI: 10.1093/mnras/sty3196, 2019b.

Hapgood, M.: The Great Storm of May 1921: An Exemplar of a Dangerous Space Weather Event, Adv. Space Res., 17, 950–975. https://doi.org/10.1029/ 2019SW002195, 2019

Love, J. J., Hayakawa, H. and Clive, E. W.: Intensity and Impact of the New York Railroad Superstorm of May 1921, Avd. Space Res, 17, 1281–1292. doi.org/10.1029/2019SW002250, 2019.

Silverman, S.M. and Cliver, E.W.: Low-latitude auroras: the magnetic storm of 14 –15 May 1921, J. Atmos. Sol-Terr. Phys. 63, 523–535, doi.org/10.1016/S1364-6826(00)00174-7, 2001

Allen, J., Frank, L., Sauer, H. and Reiff, P.: Effects of the March 1989 Solar Activity, EOS, 70, 1479-1488. doi: 10.1029/89EO004090, 1989.

R1 Line 26: About LLA, the authors state that "and have been considered a proxy of solar activity". This needs to be correctly documented. Overall, I think that this section needs to be improved and expanded with more background information.

A: We have rewritten and expanded the Background and Introduction section including an important amount of references to clarify some aspects. About the use of aurora night as a proxy we have included: "Low and mid *latitude auroras nights show an association with solar activity indices as sunspot records. This link has been observed during the telescopic era (Silverman, 1992; Lockwood and Barnard, 2015; Lockwood et al., 2016) but also in pre-telescopic era from the comparison with naked-eye sunspot reports (Hayakawa et al. 2017a; Bekli and Chadou, 2019). This relationship is due mainly to the highest frequency of LMLAs during the maximum and the decaying phase of the solar cycle (Gonzalez et al., 1994). Therefore, the mid-latitude aurorae, being footprints of solar CMEs, can be considered as proxies for the long-term solar activity. Nevertheless, LMLAs sometimes occurred in periods of low solar activity (Silverman 2003; Willis et al. 2007; Vaquero et al., 2007 and 2013; Garcia and Dryer, 1987 and Hayakawa et al., 2020). These auroras are called "sporadic auroras"".*

2 Methodology

2.1. The Observer

R1: The subsection (2.1), which is a biography of F. Rozier, is unnecessary and the text should be reduced considerably.

A: The text has been shortened a 25%.

R1: Lines 35-39: please refer to reliable sources for accurate information and remove the links.

A: A new reference: Gutton, J.P. and Bonnet, J. C., Guton J. P. (Ed): Les Lyonnaises dans l'Histoire, Privat, 1991 has been added and the links eliminated as required.

2.2. The Documentary Source and the Observation description

R1 : Lines 65-66: The book's title should be rectified as follow: Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce

A: The title has been amended ad indicated.

R1 : Lines 66-67: The subtitle should be rectified as follow: Observation sur une Nuée rendue phosphorique par une surabondance de l'électricité, vue de Beauséjour près de Beziers, le 15 Août

A: The subtitle has been modified as required.

R1: Lines 82-83: bad translation: The sentence "avant-coureurs de l'orage" means "before the storm" not "before it was orange colored"

A: The translation has been amended

R1: Line 93: The sentence "l'orage s'éloigna de Beziers" means "the storm moved away from Beziers", not "the orange moved away from Beziers"

A: The translation has been amended

R1: Line 101: why the author uses the term "explosion"?

A: The literary translation for « il n'y eut point d'explosion » is « there was no explosion". It can be also interpreted as "there was no thunder" but in those cases Rozier utilized other terms as "tonnerre".

R1: Page 2: Footnote 1: The reference must be written correctly as indicated in "Manuscript preparation guidelines for authors" of ANGEO (Publisher, Location: : :). Also, please indicate the relevant pages.

A: The footnote has been removed and the reference has been added to the reference list.

3 Analysis

R1: of the Observation Line 105: Please specify how you obtained the two values of solar depression angle (13 and 14.9).

A: The paragraph has been updated and the calculation carefully checked with the HORIZONS NASA web interface that has been quoted in the text as follows: The calculation of the solar depression angle for the geographical coordinates in Béziers and the day of the observation has been performed using the HORIZONS Web-interface of the American National Aeronautics and Space Administration (NASA) (https://ssd.jpl.nasa.gov/horizons.cgi?s_type=1#top).

R1: Lines 113-121: Color: as I said before, the orange color is not specified by the author. Therefore, this paragraph must be corrected.

A: The quote to the orange color has been cancelled and the section has been modified accordingly.

R1: Lines 133-134: There is no exact definition of the low latitude, but for me the present event must be classified as a mid-latitude aurora!

A: There is no exact definition where that boundary lies, but we agree with the referee about it is more accurate to consider the Rozier aurora as mid latitude. We have changing the text accordingly.

4 Discussion

R1: Lines 138 and 140: (Angot, 1897) not (Angot, 1896)

A: The reference has been amended: Angot A.: The Aurora Borealis, (D. Appleton & Co) 326 pp, 1897.

R1: Lines 157-160: A similar phase opposition and anti-correlation between auroral occurrence and sunspot were reported by some authors. It is an important point which must be well documented (see e.g., Silverman, S.M., 1992, Secular variation of the aurora for the past 500 Years, Rev. Geophys. 30, 333–351).

A: We have included this anticorrelation between auroral night and sunspot in the background section:

"Low and mid latitude auroras nights show an association with solar activity indices as sunspot records. This link has been observed during the telescopic era (Silverman, 1992; Lockwood and Barnard, 2015; Lockwood et al., 2016) but also in pre-telescopic era from the comparison with naked-eye sunspot reports (Hayakawa et al. 2017a; Bekli and Chadou, 2019). This relationship is due mainly to the highest frequency of LMLAs during the maximum and the decaying phase of the solar cycle (Gonzalez et al., 1994). Therefore, the mid-latitude aurorae, being footprints of solar CMEs, can be considered as proxies for the long-term solar activity. Nevertheless, LMLAs sometimes occurred in periods of low solar activity (Silverman 2003; Willis et al. 2007; Vaquero et al., 2007 and 2013; Garcia and Dryer, 1987 and Hayakawa et al., 2020). These auroras are called "sporadic auroras"".

Moreover we have modify this paragraph also the paragraph commented by the referee:

“Figure 3 shows the sunspot number during the period 1766-1800. Rozier´s observation was in the declining phase of the solar cycle 3, 2-years after the maximum. This is a good moment to see LMAA because long-lived coronal holes - source of high ionized particles in the solar wind - occur more frequently in the declining phase of the sunspot cycle (Verbanac et al., 2011; Lefèvre et al., 2016). It is important to note that the Rozier’s observation occurred in a period with few sunspot records. As we can see in Figure 4 the solar observations during the 1780`s are rare, frequently below the 30 observations per year. For this reason, any contribution to the knowledge of the geomagnetic activity in this period is very beneficial”.

R1: Overall, a more extended state of the art is needed. Some articles relating to the present work should be viewed and cited (e.g., Ordaz, J., 2010, Auroras boreales observadas en la Península Ibérica, Baleares y Canarias durante el siglo XVIII, Treb. Mus. Geol. Barcelona 17, 45-110; Legrand, J. P., & Simon, P. A., 1987, Two hundred years of auroral activity (1780-1979), AnGeo 5, 161-167; : : :)

A: The state of the art has been improved reorganizing and expanding the Background and introduction section. Both references have been included in the new version of the section.

Conclusions

R1: I think the conclusion is too short and it does not summarize the work in sufficient detail.

A: The conclusions have been rewritten as follows: “We have found a record of an atmospheric phenomenon observed on 15 August 1780 in Beausejour, close to Béziers (43º 19' N, 3º 13' E), France, by the abbot Francois Rozier described as a “big white cloud … whitish color of phosphorus burning in the open air”. Rozier was not an astronomer and it is clear that he did not fully understand the phenomenon he was recording. Probably for this reason he recorded the event with minute details to later discuss it with other academicians of his time. Thanks to this accuracy, we have been able to analyse quantitative information and facts that contribute to confirm that Francois Rozier observed a Mid latitude aurora that night. The aurora was observed during the nautical and astronomical twilight, it was white, enough brilliant to not be overshined by the full moon which however was above the horizon in ESE direction. It showed two bands and some rays which could fit with the class of auroral forms of both homogeneous arcs/uniform diffuse surface, and homogenous bands. Its temporal evolution could also resemble an auroral sub-storm expansion. This auroral event contributes to enlarge the geomagnetic knowledge of the late 18th century period in which the geomagnetic and the solar activity have high uncertainties due to few sunspot and LMLA observations reported from primary sources.

The Rozier record is a clear case of how, a scientist from a research field far from Astronomy or Meteorology in the 18th century, could record and publish descriptions on atmospheric phenomena that he did not fully understand but however he considered worth to be documented. These sources are very valuable because they report details of infrequent and/or partially unknown atmospheric phenomena. In this case the Rozier’s report had contributes to enlarge the geomagnetic knowledge of a period with low information. “

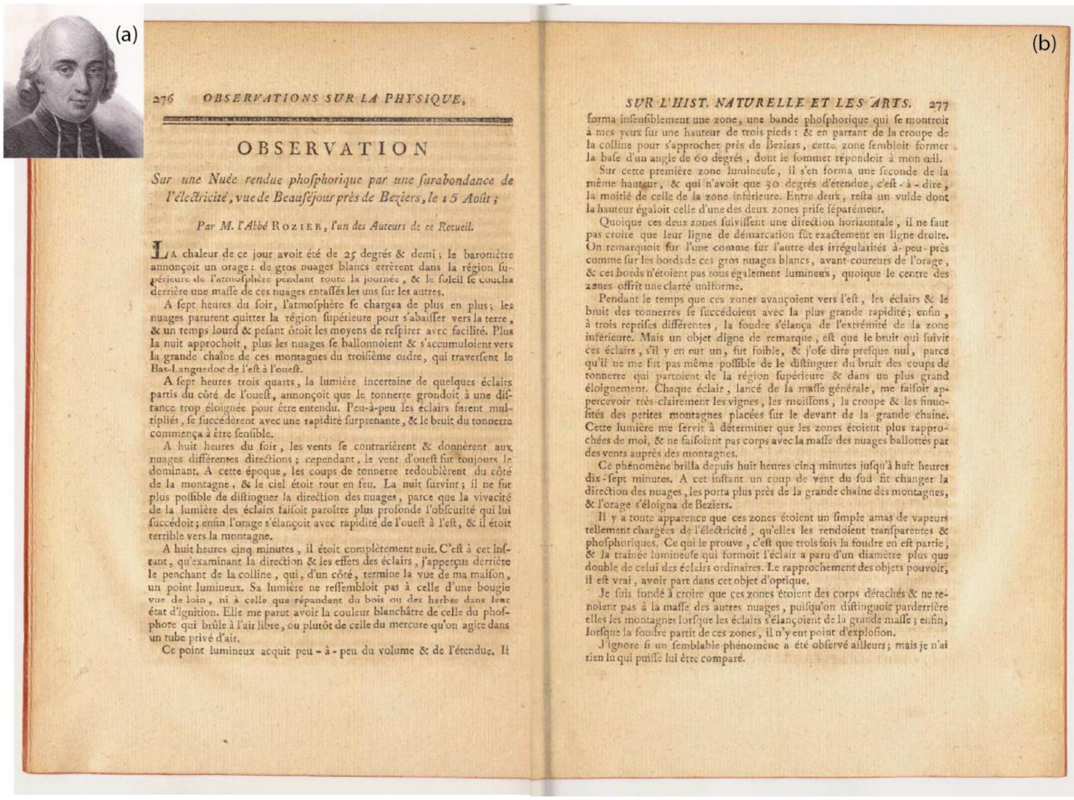
References

R1: Line 237: The source of the data (WDC-SILSO) must be cited properly as indicated on their website. I think: SILSO data/image, Royal Observatory of Belgium, Brussels. In addition, you can also indicate the version.

A: The reference has been amended.

R1: Figure 1 is not cited in the text. Furthermore, Figure 1 (b) hides part of Figure 1 (a); I think it is better to remove Figure 1 (b).

A: Figure 1 has been modified following the suggestions



276 *OBSERVATIONS SUR LA PHYSIQUE,*

OBSERVATION

Sur une Nuée rendue phoſphorique par une ſurabondance de l'électricité, vue de Beauſéjour près de Beziers, le 15 Août;

Par M. l'Abbé ROZIER, *l'un des Auteurs de ce Recueil.*

LA chaleur de ce jour avoit été de 25 degrés & demi; le baromètre annonçoit un orage: de gros nuages blancs errèrent dans la région ſupérieure de l'atmoſphère pendant toute la journée, & le ſoleil ſe coucha derrière une maſſe de ces nuages entaſſés les uns ſur les autres.

A ſept heures du ſoir, l'atmoſphère ſe chargea de plus en plus; les nuages parurent quitter la région ſupérieure pour s'abaiſſer vers la terre, & un temps lourd & peſant ôtoit les moyens de reſpirer avec facilité. Plus la nuit approchoit, plus les nuages ſe ballonnoient & s'accumuloient vers la grande chaîne de ces montagnes du troiſième ordre, qui traverſent le Bas-Languedoc de l'eſt à l'oueſt.

A ſept heures trois quarts, la lumière incertaine de quelques éclairs partis du côté de l'oueſt, annonçoit que le tonnerre grondoit à une diſtance trop éloignée pour être entendu. Peu-à-peu les éclairs furent multipliés, ſe ſuccédèrent avec une rapidité ſurprenante, & le bruit du tonnerre commença à être ſenſible.

A huit heures du ſoir, les vents ſe contrarièrent & donnèrent aux nuages différentes directions; cependant, le vent d'oueſt fut toujours le dominant. A cette époque, les coups de tonnerre redoublèrent du côté de la montagne, & le ciel étoit tout en feu. La nuit ſurvint; il ne fut plus poſſible de diſtinguer la direction des nuages, parce que la vivacité de la lumière des éclairs faiſoit paroître plus profonde l'obſcurité qui lui ſuccédoit; enfin l'orage s'élançoit avec rapidité de l'oueſt à l'eſt, & il étoit terrible vers la montagne.

A huit heures cinq minutes, il étoit complètement nuit. C'eſt à cet inſtant, qu'examinant la direction & les effets des éclairs, j'apperçus derrière le penchant de la colline, qui, d'un côté, termine la vue de ma maiſon, un point lumineux. Sa lumière ne reſſembloit pas à celle d'une bougie vue de loin, ni à celle que répandent du bois ou des herbes dans leur état d'ignition. Elle me parut avoir la couleur blanchâtre de celle du phoſphore qui brûle à l'air libre, ou plutôt de celle du mercure qu'on agite dans un tube privé d'air.

Ce point lumineux acquit peu-à-peu du volume & de l'étendue. Il

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forma inſenſiblement une zone, une bande phoſphorique qui ſe montroit à mes yeux ſur une hauteur de trois pieds: & en partant de la croupe de la colline pour s'approcher près de Beziers, cette zone ſembloit former la baſe d'un angle de 60 degrés, dont le ſommet répondoit à mon œil.

Sur cette première zone lumineuſe, il s'en forma une ſeconde de la même hauteur, & qui n'avoit que 30 degrés d'étendue, c'eſt-à-dire, la moitié de celle de la zone inférieure. Entre deux, reſta un vuide dont la hauteur égaloit celle d'une des deux zones priſe ſéparément.

Quoique ces deux zones ſuiviſſent une direction horizontale, il ne faut pas croire que leur ligne de démarcation fût exactement en ligne droite. On remarquoit ſur l'une comme ſur l'autre des irrégularités à-peu-près comme ſur les bords de ces gros nuages blancs, avant-coureurs de l'orage, & ces bords n'étoient pas tous également lumineux, quoique le centre des zones offrît une clarté uniforme.

Pendant le temps que ces zones avançoient vers l'eſt, les éclairs & le bruit des tonnerres ſe ſuccédoient avec la plus grande rapidité; enfin, à trois repriſes différentes, la foudre s'élança de l'extrémité de la zone inférieure. Mais un objet digne de remarque, eſt que le bruit qui ſuivit ces éclairs, s'il y en eut un, fut foible, & j'oſe dire preſque nul, parce qu'il ne me fut pas même poſſible de le diſtinguer du bruit des coups de tonnerre qui partoient de la région ſupérieure & dans un plus grand éloignement. Chaque éclair, lancé de la maſſe générale, me faiſoit appercevoir très-clairement les vignes, les moiſſons, la croupe & les ſinuoſités des petites montagnes placées ſur le devant de la grande chaîne. Cette lumière me ſervit à déterminer que les zones étoient plus rapprochées de moi, & ne faiſoient pas corps avec la maſſe des nuages ballottés par des vents auprès des montagnes.

Ce phénomène brilla depuis huit heures cinq minutes juſqu'à huit heures dix-ſept minutes. A cet inſtant un coup de vent du ſud fit changer la direction des nuages, les porta plus près de la grande chaîne des montagnes, & l'orage s'éloigna de Beziers.

Il y a toute apparence que ces zones étoient un ſimple amas de vapeurs tellement chargées de l'électricité, qu'elles les rendoient tranſparentes & phoſphoriques. Ce qui le prouve, c'eſt que trois fois la foudre en eſt partie, & la traînée lumineuſe qui formoit l'éclair a paru d'un diamètre plus que double de celui des éclairs ordinaires. Le rapprochement des objets pouvoit, il eſt vrai, avoir part dans cet objet d'optique.

Je ſuis fondé à croire que ces zones étoient des corps détachés & ne tenoient pas à la maſſe des autres nuages, puiſqu'on diſtinguoit parderrière elles les montagnes lorſque les éclairs s'élançoient de la grande maſſe; enfin, lorſque la foudre partit de ces zones, il n'y eut point d'exploſion.

J'ignore ſi un ſemblable phénomène a été obſervé ailleurs; mais je n'ai rien lu qui puiſſe lui être comparé.

Figure 1: (a) Photographic portrait of Abbot Francois Rozier (photo in public domain) (Library of Congress Prints and Photographs Division Washington; http://loc.gov/pictures/resource/ppmsca.02227/). (b) The two printed pages reporting the aurora observation made by Abbot Francois Rozier, on 15 August 1780 in Beziers, France (Rozier, 1781**).**

An Early Mid Latitude Aurora Observed by Rozier (Béziers, 1780)

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Abstract. Aurorae Observations are an uncommon phenomenon at low and mid latitudes that, at the end of the 18th century was not well known and understood. Low and Mid geomagnetic latitude Aurorae observations provide information about episodes of intense solar storms associated with flares and outstanding coronal mass ejection (CME) and on the variation of the geomagnetic field. However, for many observers at mid and low latitude, the features of a northern light were unknown, so they could easily report it as a phenomenon without explanation. In this work, we found that an earlier Mid geomagnetic latitude aurora was observed in Beausejour, close to Béziers (43º 19′ N, 3º 13′ E), France, by the abbot Francois Rozier. He was a meticulous botanist, doctor and agronomist with special interest in atmospheric phenomena. On 15 August 1780, from 19:55 to 20:07 (Universal Time), Francois Rozier observed a "phosphoric cloud". A careful analysis of the report points out that he was reporting an auroral event. The recovery of auroral events at low and mid latitude during the 1780's is very useful to shed light to the solar activity during this period because there are few records of sunspot observations.

1 Background and Introduction

Incursions of high-energy particles from space, mainly solar wind, strongly interact with the Earth's magnetosphere, causing ionization and excitation of atmospheric gases and auroral emissions (Brekke, 2013; Gonzalez et al., 1994). The aurora borealis is a spectacular phenomenon that have been recorded from the Assyrians and Babylonians (Stephenson et al., 2004; Hayakawa et al. 2016; Hayakawa et al. 2019c) till nowadays. However, it is not until 1733 when Mairan (1733) suggested that the aurora could be caused by the solar atmosphere (Krivsky, 1984).

Low and Mid latitude auroras (LMLAs) are usually associated with intense space weather events, frequently caused by coronal mass ejections (CME) (Gonzalez et al., 1994; Daglis, 1999; Vázquez et al. 2006). This was the case of well studied extreme space weather events as those occurred on September 1770 (Hayakawa et al. 2017a); the Carrington event in August/September 1859 (Green and Boardsen, 2006; Green et al., 2006; Humble 2006; Tsurutani et al., 2003; Cliver and Dietrich, 2013; Hayakawa et al., 2019a); the storm on 1872 February (Hayakawa et al. 2018; Silverman, 2008); the extreme event on September 1909 (Hayakawa et al., 2019b); May 1921 (Hapgood, 2019; Silverman and Cliver, 2001; Love et al., 2019) or March 1989 (Allen et al., 1989) resulting in extreme magnetic disturbances and auroral displays at very low latitudes. It is important to note that extreme space weather events of these magnitude can provoke important impacts on our highly technological dependent society, especially in activities related with the aviation, the GPS signals, radio communication, and the electric power grid (Baker et al., 2008; Ridley et al., 2018).

Low and mid latitude auroras nights show an association with solar activity indices as sunspot records. This link has been observed during the telescopic era (Silverman, 1992; Lockwood and Barnard, 2015; Lockwood et al., 2016) but also in pre-telescopic era from the comparison with naked-eye sunspot reports (Hayakawa et al. 2017a; Bekli and Chadou, 2019). This relationship is due mainly to the highest frequency of LMLAs during the maximum and the decaying phase of the solar cycle (Gonzalez et al., 1994). Therefore, the mid-latitude aurorae, being footprints of solar CMEs, can be considered as proxies for the long-term solar activity. Nevertheless, LMLAs sometimes occurred in periods of low solar activity (Silverman 2003; Willis et al. 2007; Vaquero et al., 2007 and 2013; Garcia and Dryer, 1987 and Hayakawa et al., 2020). These auroras are called "sporadic auroras".

Auroral catalogues are important tool to understand the long-term interaction among the solar activity and the Earth's magnetosphere (Legrand and Simon 1987, Silverman S.M. 1992). In the last centuries many auroral catalogues have been developed e.g. Mairan (1733), Lovering (1866), Fritz (1873), Angot (1897), Tromholt (1902), Link (1962, 1964), Krivsky & Pejml (1988), Loysha et al. (1989) or Ordaz (2010). LMLAs, although rare, are recorded in these catalogues by professional and non-professional observers. During the 18th century, in Europe, there were some professional observers who were familiar with the phenomenon and who recorded auroras systematically e.g. Francisco Salvà (Barcelona, Spain) (Vaquero et al., 2010) and Giuseppe Toaldo (Padova, Italy) (Domínguez-Castro et al., 2016). Nevertheless, there were many sporadic observers that also recorded LMLAs unknowingly, cataloging them as strange and inexplicable phenomena. These sporadic reports are important to generate and extend LMLAs catalogues but require an accurate analysis to avoid possible misinterpretations (Kawamura et al., 2016; Usoskin et al., 2017; Stephenson et al., 2019). Here, we analyzed an observation made by the Abbot Francois Rozier in 1780 with enough details and quantifiable information to understand if he observed a LMLA or a different phenomenon.

2 Methodology

2.1. The Observer

Jean-Baptiste François Rozier, (Lione, 23 January 1734 - Lione, 29 September 1793) (Fig. 1a) (Gutton and Bonnet, 1991) was a professor of Botanic and Medicine at the University of Lione that after studying at the Jesuit college at Villefranche-sur-Saône entered the the Saint-Irénée seminary in Lyon. In 1771 Rozier moved to Paris to edit the Journal de Physique et d' Histoire Naturelle founded by Jacques Gautier d' Agoty; after becoming the journal owner he renamed it as *Journal d' Observations sur la Physique, l' Histoire Naturelle et sur les Arts et Métier*s and later as the *Journal de Physique* where the original versions of many fundamental memoirs appeared (McKie, 1957). Rozier maintained the journal up to 1779 when he devoted himself to the writing of the *Cours d' agriculture* (see below) a periodical that was edited by his nephew, the mineralogist and priest Jean-André Mongez (21 November 1750 – May 1788). In 1779 he became prior of the abbey at Nanteuil-le-Haudouin (between Paris and Reims), while in July 1780 Rozier bought an estate close in Beauséjour, in the suburb of Béziers (43°19′ N, 3°13′ E), Southern France (domaine de Beauséjour) to install his own model farm (1781). Here he could edit his *Cours Complet d' Agriculture Théorique et Pratiqueou Dictionnaire Reisonné et Universel d' Agriculture* (twelve volumes in form of a dictionary, of which nine were by Rozier himself, 1781–1800, and the last two were published after his death). Finally, he sold the property and in 1786 moved to Lyon where he accepted a position as Director of the School of Agriculture and of the Pépinière (plant nursery) de la Province in 1788. Finally, he became constitutional curate of Sainte-Polycarpe parish in Lyon and was killed during the siege of the town the night between the 28th and 29th of September 1793 (French Revolution).

Rozier was a member of the Académie de Lyon and thanks to his activity as editor of scientific journals was in contact with the most famous scientists and intellectuals of his times. He devoted his life to the observation of botanical or agricultural biological, chemical, physical and meteorological phenomena (e.g. temperature, atmospheric pressure observations with barometers of different diameters or state of the sky as thunders` observations).

2.2. The Documentary Source and the Observation description

The observation was described in the "*Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce*" tome XVIII under the title "*Observation sur une Nuée rendue phosphorique par une surabondance de l'électricité, vue de Beauséjour près de Béziers, le 15 Août* " [About a cloud rendered phosphoric by an overabundance of electricity observed at Béziers the 15th of August] (Rozier, 1781) (Fig. 1b). The most important fragments of the observation are reported below in our English translation, while the complete original French version is reported in Figure 1b.

"*The closer the night approached, the more the clouds were pushed and accumulated towards the great chain of mountains of the third order that cross the low-Languedoc from east to west... At 20:05 it was completely night. It was at this moment that, examining the direction and the effects of the flashes, I noticed behind the slope of the hill, which on one side blocks the view from my house, a bright spot. This light did not look like that of a candle seen from afar, nor that which spreads from a forest or grass when they are set on fire. It seemed to me to have the whitish color of phosphorus burning in the open air, or rather of that of mercury stirred in a tube without air. This bright spot gradually acquired volume and intensity. It imperceptibly formed an area, a phosphoric band that appeared to my eyes at a height of 3 feet: and starting from the top of the hill almost to Béziers, this area seemed to form the base of a 60° angle, whose summit responded to my eye.*

On this first luminous area, a second one of the same height formed, and it had only 30° of extension [width], or half of that of the lower area. Between them remained a void whose height equaled that one of the two areas considered separately.

Even if these two zones followed a horizontal direction, it is not to believed that their line of demarcation followed exactly a straight line. We noticed on both some irregularities, roughly as on the edges of that big white cloud, storm forerunners, and these edges were not all equally bright even if the center of the zones showed a uniform light.

During the period of time when these areas were moving eastward, the lightning and thunder noise were more rapid; finally, at three different times, a flash started from the end of the lower area. But an object worthy of note is that the noise following these flashes, if there was one, was weak and I would dare to say almost null because I could not distinguish it from the *noise of the thunder that was starting from the upper region and from a greater distance. Every flash, launched by the general mass, made me clearly appreciate the vines, the crops, the top and the sinuosity of the small mountains located in front of the big chain.*

That light helped me to understand that the areas were closer to me and did not belong to the mass of clouds pushed by the winds towards the mountain.

This phenomenon was shown from 20.05 until 20.17. In this instant a blow of wind from the south changed the direction of the clouds, bringing them closer to the big mountain chain, and the storm moved away from Beziers.

It would seem that these areas were a simple mass of vapors, only charged by electricity, which made them transparent and phosphoric. It is proven by the fact that three times the flash disappeared and the trail of light left by the flash appeared to be more than twice the diameter of normal flashes. The [apparent] proximity of the objects could, it is true, be due to these optical effects.

I am led to believe that these areas were detached entities [bodies] and that they did not belong to the mass of the other clouds because the mountains were visible behind them when the flash departed from the big mass; finally, when the flash started from these areas, there was no blast.

I don't know if such a phenomenon has been observed elsewhere; but I never read anything that can be compared to it."

3 Analysis of the Observation

Hour of Observation and sun depression angle: Rozier describes the starting (20:05) and ending (20:17) hour of his observation as local solar time (LST) i.e. the measure of local time as in use in the XVIII century. The pendulum clocks locally could be synchronized following the daily data reported in the Ephemerides with the time of the sunrise, midday and sunset published yearly (Jeaurat, 1780). Given its longitude, these times correspond to 19:55 and 20:07 in Universal Time (UT) respectively. At these times the solar depression angle was 11.5° and 13.3° respectively. Therefore, although Rozier described the observational conditions as if it was "completely night", however the observation started during the nautical twilight and concluded in the astronomical twilight. The calculation of the solar depression angle for the geographical coordinates in Béziers and the day of the observation has been performed using the HORIZONS Web-interface of the American National Aeronautics and Space Administration (NASA) (https://ssd.jpl.nasa.gov/horizons.cgi?s_type=1#top).

Shape: Related to the shape description, Rozier was very accurate. The main structure described by Rozier is : "*it formed a zone, a phosphoric band…at a height of 3 feet….and finally it formed an angle of 60°…. above this first luminous zone a second* [zone] *of the same height was formed, but with 30° of extension only i.e. half of that of the lower zone. Between one and the other a void remained, the height of which matched that one of the two connected zones*". This description may fit with the report of the auroral forms class without ray structure i.e. homogeneous arcs or uniform diffuse surface, and homogenous bands too (Störmer, 1955).

Nevertheless the beginning of the aurora could resemble some aspect of an auroral sub-storm expansion (Ebihara et al., 2017 and Stephenson et al., 2019) which is characterized by initial brightening of aurora, followed by a bulge expanding in all directions (Akasofu, 1964; Akasofu et al., 1965) "*I noticed a luminous point…this luminous point acquired slowly* [over time] *volume and intensity".* Moreover, Rozier records some flaming during the event "*in one or in the other zone I noticed irregularities, as well as on the edges of those big white clouds* [i.e. general mass or bulge]. *This edge was not homogeneously bright, although in the center presented uniform bright. In the time over which the zones moved Eastward…. a flash started from the end of the lower area* [of the general mass or bulge]".

Color: He carefully mentioned the color: "*whitish color of phosphorus burning in the open air*". As stated by Stephenson et al. 2019 at Low-Mid geomagnetic latitude, northern lights have generally higher probability to be observed if they are reddish, however in case of an auroral display without enough brightness, it tends to appear whitish to the human eye. In addition, such effect of the human eye is enhanced if the moon is also present in the sky as the eye cannot be "dark adapted". Moreover, the whitish auroral color may be explained with the enhancement of the 557.7 nm of Oxygen with weak brightness or due to the Oxygen mixture with other emissions as well (Ebihara et al., 2017; Stephenson et al., 2019). Examples of observation which confirm that LMLA are whitish in color during extreme space weather events are reported by Ebihara et al. 2017; Green and Boardsen, 2006; Hayakawa et al. 2017b and Willis et al.1996. Rozier observed a white aurora, this made the phenomena more unusual and increase the possibility of misinterpretation of the phenomenon by Rozier himself.

Noise: Silverman and Tuan (1973) said that from observational evidence, the most likely sound accompany auroral observations could derive from discharges generated by aurorally associated electric fields. Rozier, although in his observation reported: *"It appeared* [to me] *that these areas were a simple mass of steam, only charged by electricity, which it made them transparent and phosphoric".* However, he concluded saying that: *"for three different times, a flash, with almost null noise, started from the end of the lower area* [i.e. the bulge] … [and again] *when the light flashed …there was no blast".* This absence of sound recorded by Rozier discard a possible misinterpretation with other noisy atmospheric phenomena.

Moon: whether or not an aurora is overshined by the moon depends on the lunar phase, the brightness of the aurora, and the angular distance between the moon and the sky position occupied by auroral emission (Stephenson et al. 2019). Rozier does not report any information about the moon. But the moon was in the sky that day. The moon, on 15 August 1780 was full moon and rose at 19:25 (UT) at an azimuth angle of 111.4° ESE direction, i.e. opposite respect the direction of observation of Rozier and close to the horizon. During the time Rozier observed the phenomenon, the moon was at azimuth angle 116.5° and elevation angle 3.4° (at 19:55 UT) while at the end of his observation it was at azimuth angle 118.5° and elevation angle 5.3° (at 20:07 UT) therefore always in the direction ESE. The short time of the observation suggests that although the aurora was highly bright because Rozier could record it with full moon in the sky (Stephenson et al., 2019; Hattori et al., 2019), however because of the moon rise above the horizon the light conditions could hinder the visibility of the aurora as well as the presence of tropospheric clouds. In literature several auroral observations are reported during full moon e.g. those observed on the 18 February and on 12 November 1837 (Olmsted, 1837; Snow, 1842), those reported by Martin, 1847 and Glaisher, 1847 on October 24 of that year, and the event observed on 4 September 1908 described by Barnard, 1910.

Geomagnetic latitude: We have calculated the temporal evolution of the geomagnetic latitude in Beziers for the night of the observation using the geomagnetic model gufm1 (Jakson et al., 2000). The geomagnetic latitude, φ equals to 50,18°N is obtained by equation (2) in the hypothesis of a dipolar configuration for the geomagnetic field.

$$\boldsymbol{\varphi = \frac{\tan I}{2}} \qquad (2)$$

where I is the magnetic inclination obtained from the gufm1 model for the year 1780. This implies that the aurora is in the lower limit of the mid-latitude aurora or at the border for being defined LLA as this threshold often in literature is around 50,00°N of geomagnetic latitude.

4 Discussion

In the previous section we have verified that Rozier observed an aurora the night of the 15 August 1780. According with the Angot catalogue (Angot, 1897) in this night the aurora was also observed at Ratisbon (Germany, 49º 01' N, 12° 05' E), 5.5° further north than Beziers. The Angot catalogue has been extensively used on the reconstruction of auroral nights and as a proxy of the long-term geomagnetic variability. Nevertheless, it is important to note that Angot (1897) is a secondary source (the author was no witness of the facts he describes) and does not provide information on the primary sources he consulted for the elaboration of the catalogue. Secondary sources must be used carefully because can include errors due to the transcription or interpretation of the primary source. For this reason, it is valuable to found primary sources that corroborate the information provided by Angot, specially during the nights in which Angot recorded an event in a single location, as the night of 15 August 1780.

In addition, magnetic indexes are not available in 1780. The Ak index is in fact available since 1844 (Nevanlinna & Kataja, 1993), the aa index since 1868 (Mayaud, 1980) and the geomagnetic IDV index (Svalgaard & Cliver, 2010) is available since 1835. For this reason, LMLAs catalogues and sunspot number are used here as proxies of the geomagnetic activity at Rozier's times.

First the aurorae catalogue at comparable latitudes have been analyzed. Then, they were compared with two existing coeval series of auroras homogeneously recorded at low latitude by trained observers as Toaldo (1766-1797) (Padova, Italy 45º 24' N, 11º 52' E) (Domínguez-Castro et al., 2016) and Salvà (1780-1825) (Barcelona, Spain 41º 23' N, 2º 10' E) (Vaquero et al, 2010). For differentiation purpose, the additional series of auroras observed by Thomas Hughes from Stroud, United Kingdom (mid-latitude 51,75°N, 2,22°W) (Giles, 2005) has been also reported. Figure 2 shows the Toaldo, Salva and

Hughes yearly total observations of auroras and the geomagnetic latitude respectively in Padua, Barcelona, Stroud and Beziers over the common 1766-1800 period. The Rozier's observation was close to the maximum LLA observed by Toaldo in Padova (1779). Nevertheless, no aurora was recorded by Salvà at Barcelona during 1780. At higher latitudes (Stroud) Hughes recorded a mean low activity of auroras for that year.

Figure 3 shows the sunspot number during the period 1766-1800. Rozier´s observation was in the declining phase of the solar cycle 3, 2-years after the maximum. This is a good moment to see LMAA because long-lived coronal holes - source of high ionized particles in the solar wind - occur more frequently in the declining phase of the sunspot cycle (Verbanac et al., 2011; Lefèvre et al., 2016). It is important to note that the Rozier's observation occurred in a period with few sunspot records. As we can see in Figure 4 the solar observations during the 1780`s are rare, frequently below the 30 observations per year. For this reason, any contribution to the knowledge of the geomagnetic activity in this period is very beneficial.

Figure 4 shows at monthly resolution the solar activity and the auroras recorded in Padova from August 1779 to August 1781. We can see that no aurora was observed during August and only one solar observation was recorded in this month. The nearest solar observation was the 30th of August when J.C. Staudach report 4 groups in the solar disk. The previous observation was done by P. Zeno at 12th of July recording one group (Vaquero et al., 2016). It means this event occurred in an interval without sunspots data for 48 days.

Conclusions

We have found a record of an atmospheric phenomenon observed on 15 August 1780 in Beausejour, close to Béziers (43º 19′ N, 3º 13′ E), France, by the abbot Francois Rozier described as a "*big white cloud … whitish color of phosphorus burning in the open air*". Rozier was not an astronomer and it is clear that he did not fully understand the phenomenon he was recording. Probably for this reason he recorded the event with minute details to later discuss it with other academicians of his time. Thanks to this accuracy, we have been able to analyse quantitative information and facts that contribute to confirm that Francois Rozier observed a Mid latitude aurora that night. The aurora was observed during the nautical and astronomical twilight, it was white, enough brilliant to not be overshined by the full moon which however was above the horizon in ESE direction. It showed two bands and some rays which could fit with the class of auroral forms of both homogeneous arcs/uniform diffuse surface, and homogenous bands. Its temporal evolution could also resemble an auroral sub-storm expansion.

This auroral event contributes to enlarge the geomagnetic knowledge of the late 18th century period in which the geomagnetic and the solar activity have high uncertainties due to few sunspot and LMLA observations reported from primary sources.

The Rozier record is a clear case of how, a scientist from a research field far from Astronomy or Meteorology in the 18th century, could record and publish descriptions on atmospheric phenomena that he did not fully understand but however he considered worth to be documented. These sources are very valuable because they report details of infrequent and/or partially unknown atmospheric phenomena. In this case the Rozier's report had contributes to enlarge the geomagnetic knowledge of a period with low information.

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Authors contributions

C. Bertolin conceived the study, performed the analysis and drafted the manuscript with F. Dominguez-Castro, who wrote the final manuscript.

L. de Ferri translated the original data and conducted the historical research used in the study as well as contributed to scientific discussion of the article together with C. Bertolin and F. Dominguez-Castro.

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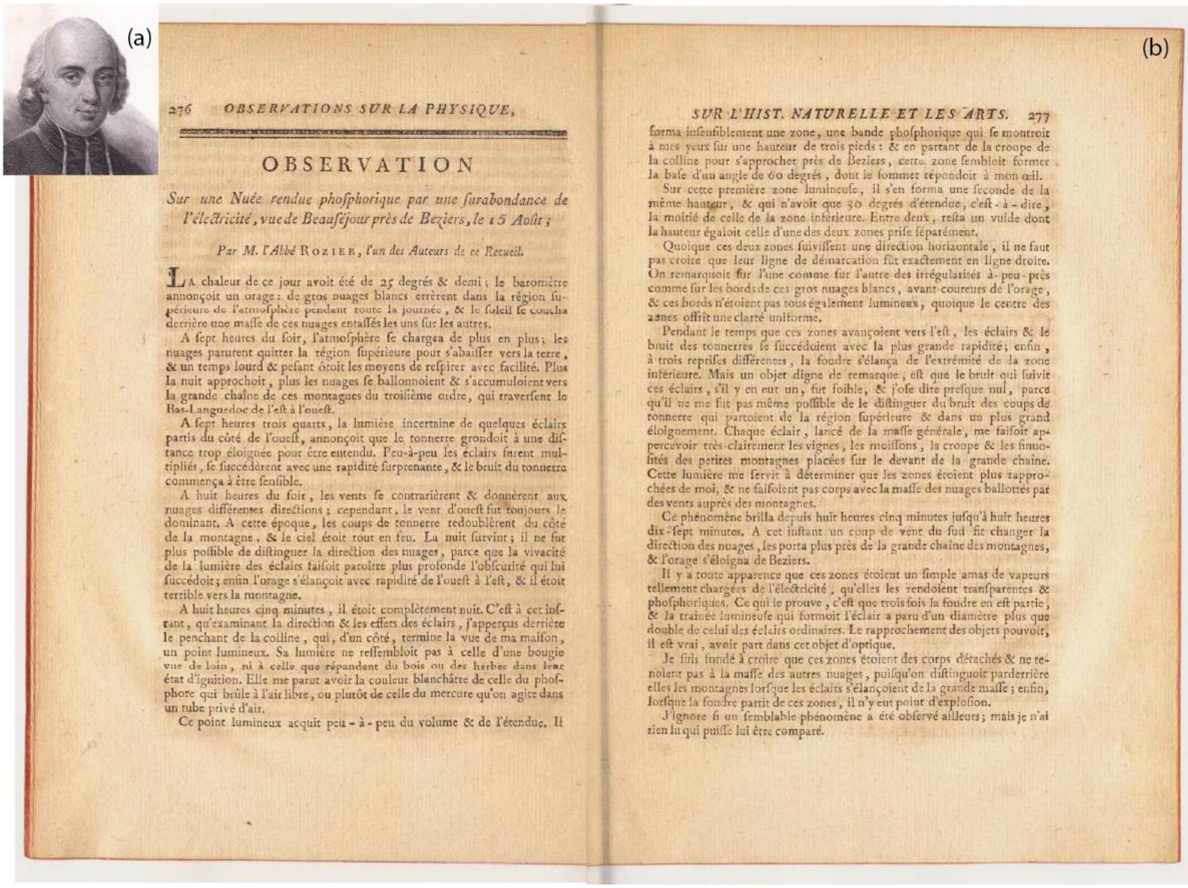

276 OBSERVATIONS SUR LA PHYSIQUE,

OBSERVATION

Sur une Nuée rendue phoſphorique par une ſurabondance de l'électricité, vue de Beauſéjour près de Beziers, le 15 Août;

Par M. l'Abbé ROZIER, *l'un des Auteurs de ce Recueil.*

La chaleur de ce jour avoit été de 25 degrés & demi; le baromètre annonçoit un orage: de gros nuages blancs errèrent dans la région ſupérieure de l'atmoſphère pendant toute la journée, & le ſoleil ſe coucha derrière une maſſe de ces nuages entaſſés les uns ſur les autres.

A ſept heures du ſoir, l'atmoſphère ſe chargea de plus en plus; les nuages parurent quitter la région ſupérieure pour s'abaiſſer vers la terre, & un temps lourd & peſant ôtoit les moyens de reſpirer avec facilité. Plus la nuit approchoit, plus les nuages ſe ballonnoient & s'accumuloient vers la grande chaîne de ces montagnes du troiſième ordre, qui traverſent le Bas-Languedoc de l'eſt à l'oueſt.

A ſept heures trois quarts, la lumière incertaine de quelques éclairs partis du côté de l'oueſt, annonçoit que le tonnerre grondoit à une diſtance trop éloignée pour être entendu. Peu-à-peu les éclairs furent multipliés, ſe ſuccédèrent avec une rapidité ſurprenante, & le bruit du tonnerre commença à être ſenſible.

A huit heures du ſoir, les vents ſe contrarièrent & donnèrent aux nuages différentes directions; cependant, le vent d'oueſt fut toujours le dominant. A cette époque, les coups de tonnerre redoublèrent du côté de la montagne, & le ciel étoit tout en feu. La nuit ſurvint; il ne fut plus poſſible de diſtinguer la direction des nuages, parce que la vivacité de la lumière des éclairs faiſoit paroître plus profonde l'obſcurité qui lui ſuccédoit; enfin l'orage s'élançoit avec rapidité de l'oueſt à l'eſt, & il étoit terrible vers la montagne.

A huit heures cinq minutes, il étoit complètement nuit. C'eſt à cet inſtant, qu'examinant la direction & les effets des éclairs, j'apperçus derrière le penchant de la colline, qui, d'un côté, termine la vue de ma maiſon, un point lumineux. Sa lumière ne reſſembloit pas à celle d'une bougie vue de loin, ni à celle que répandent du bois ou des herbes dans leur état d'ignition. Elle me parut avoir la couleur blanchâtre de celle du phoſphore qui brûle à l'air libre, ou plutôt de celle du mercure qu'on agite dans un tube privé d'air.

Ce point lumineux acquit peu-à-peu du volume & de l'étendue. Il

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forma inſenſiblement une zone, une bande phoſphorique qui ſe montroit à mes yeux ſur une hauteur de trois pieds: & en partant de la croupe de la colline pour s'approcher près de Beziers, cette zone ſembloit former la baſe d'un angle de 60 degrés, dont le ſommet répondoit à mon œil.

Sur cette première zone lumineuſe, il s'en forma une ſeconde de la même hauteur, & qui n'avoit que 30 degrés d'étendue, c'eſt-à-dire, la moitié de celle de la zone inférieure. Entre deux, reſta un vuide dont la hauteur égaloit celle d'une des deux zones priſe ſéparément.

Quoique ces deux zones ſuiviſſent une direction horizontale, il ne faut pas croire que leur ligne de démarcation fût exactement en ligne droite. On remarquoit ſur l'une comme ſur l'autre des irrégularités à-peu-près comme ſur les bords de ces gros nuages blancs, avant-coureurs de l'orage, & ces bords n'étoient pas tous également lumineux, quoique le centre des zones offrît une clarté uniforme.

Pendant le temps que ces zones avançoient vers l'eſt, les éclairs & le bruit des tonnerres ſe ſuccédoient avec la plus grande rapidité; enfin, à trois repriſes différentes, la foudre s'élança de l'extrémité de la zone inférieure. Mais un objet digne de remarque, eſt que le bruit qui ſuivit ces éclairs, s'il y en eut un, fut foible, & j'oſe dire preſque nul, parce qu'il ne me fut pas même poſſible de le diſtinguer du bruit des coups de tonnerre qui partoient de la région ſupérieure & dans un plus grand éloignement. Chaque éclair, lancé de la maſſe générale, me faiſoit appercevoir très-clairement les vignes, les moiſſons, la croupe & les ſinuoſités des petites montagnes placées ſur le devant de la grande chaîne. Cette lumière me ſervit à déterminer que les zones étoient plus rapprochées de moi, & ne faiſoient pas corps avec la maſſe des nuages ballottés par des vents auprès des montagnes.

Ce phénomène brilla depuis huit heures cinq minutes juſqu'à huit heures dix-ſept minutes. A cet inſtant un coup de vent du ſud fit changer la direction des nuages, les porta plus près de la grande chaîne des montagnes, & l'orage s'éloigna de Beziers.

Il y a toute apparence que ces zones étoient un ſimple amas de vapeurs tellement chargées de l'électricité, qu'elles les rendoient tranſparentes & phoſphoriques. Ce qui le prouve, c'eſt que trois fois la foudre en eſt partie, & la traînée lumineuſe qui formoit l'éclair a paru d'un diamètre plus que double de celui des éclairs ordinaires. Le rapprochement des objets pouvoit, il eſt vrai, avoir part dans cet objet d'optique.

Je ſuis fondé à croire que ces zones étoient des corps détachés & ne tenoient pas à la maſſe des autres nuages, puiſqu'on diſtinguoit parderrière elles les montagnes lorſque les éclairs s'élançoient de la grande maſſe; enfin, lorſque la foudre partit de ces zones, il n'y eut point d'exploſion.

J'ignore ſi un ſemblable phénomène a été obſervé ailleurs; mais je n'ai rien lu qui puiſſe lui être comparé.

Figure 1: (a) Photographic portrait of Abbot Francois Rozier (photo in public domain) Library of Congress Prints and Photographs Division Washington. (b) The two printed pages reporting the aurora observation made by Abbot Francois Rozier, on 15 August 1780 in Beziers, France (Rozier, 1781).

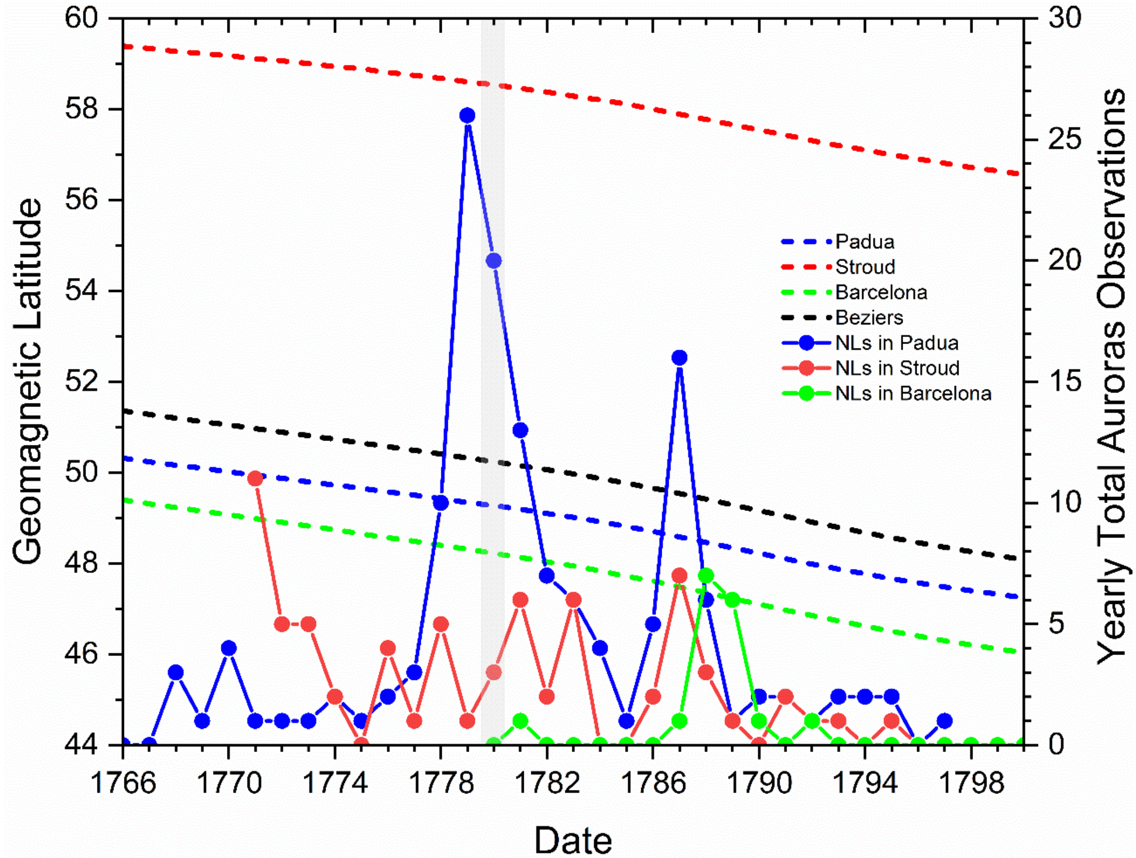

Figure 2: Geomagnetic Latitude variations for Padua, Barcelona Stroud and Beziers and yearly total auroras recorded in these places by Toaldo, Salva and Hughes. The grey column remarks the year of the Rozier's auroral observation 1780.

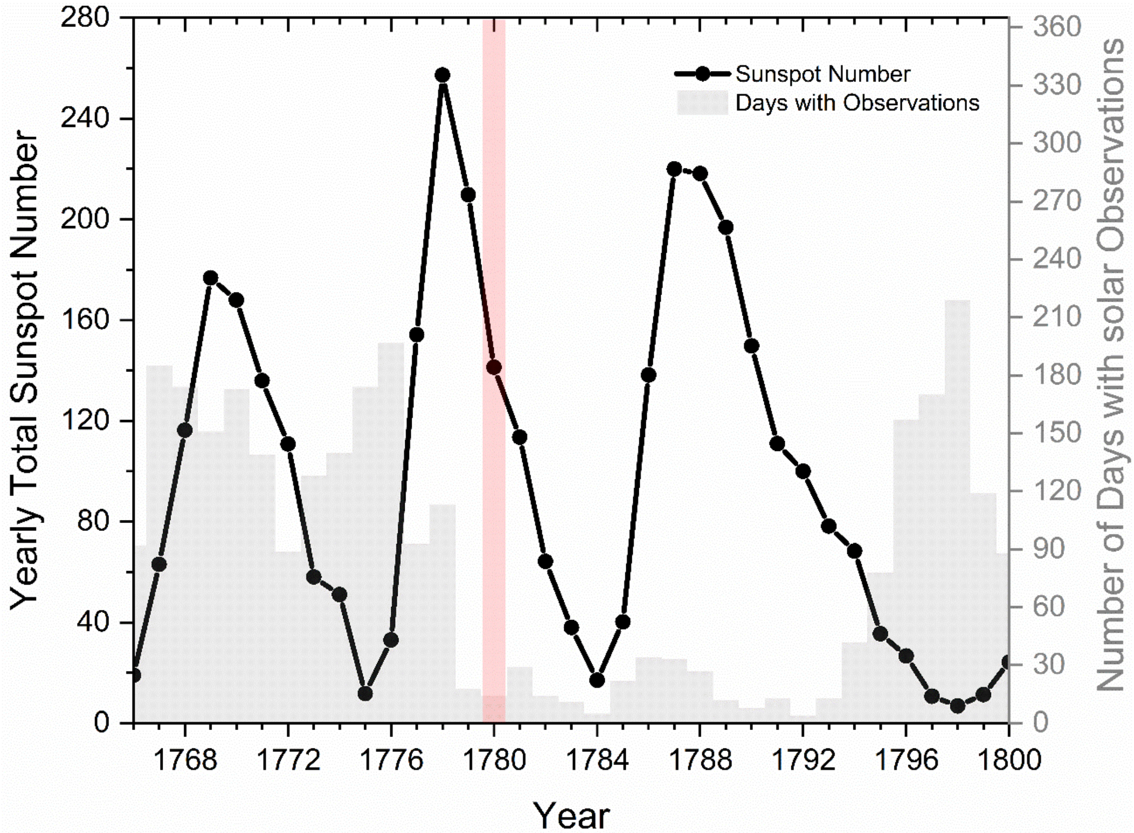

Figure 3: Annual sunspot numbers and number of days with solar observations (SILSO –WDC ; Clette et al.,2014; Clette and Lefevre 2016).

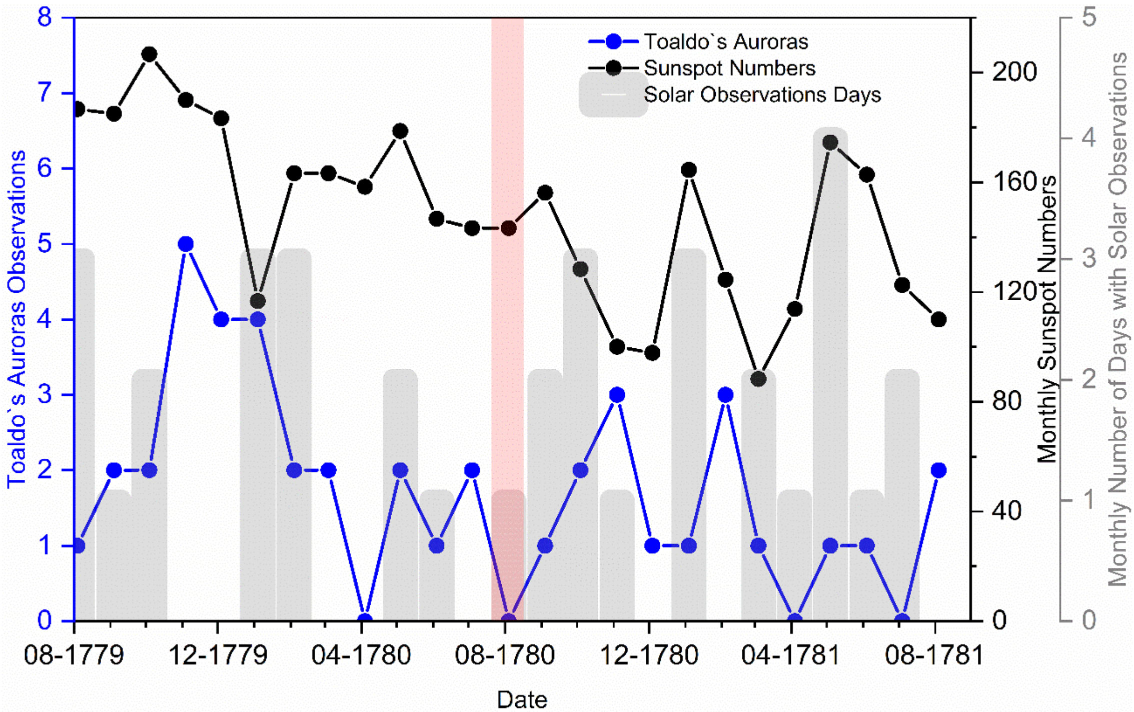

Figure 4: Monthly sunspot numbers, days with solar observations and auroras from Toaldo catalogue from August 1779 to August 1781 (Dominguez-Castro et al., 2016; Vaquero et al. 2016

Dear Editor,

The authors want to thank the reviewers for their work on the submitted paper.

In the following, specific answers to the comments are reported and all changes in the new revised manuscript are highlighted in yellow.

Reviewer #2:

Referee Report on MS angeo-2019-97 "An Early Low Latitude Aurora Observed by Rozier (Beziers, 1780)" by Bertolin et al.

General Comments

R2: This is an interesting case report for the mid-latitude aurora on 1780 August 15 likely at Beauséjour near Béziers. The mid-latitude auroral report in 1780 is especially important, as this will be a footprint of solar eruption and a hint for contemporary solar activity where we do not have enough coverage of sunspot observations. Overall, I think this manuscript will be an interesting contribution, while further clarifications and explanations are needed both on its background and discussions. I have listed my comments below and wish the authors to address them. Their language needs to be improved as well, preferably with professional grammatical proofreading.

A: Thank you very much for this constructive report. We answered all the comments pointed out by you. We put special attention in the reorganization and improvement of the background and the discussion. The full text of the paper was revised by an English mother tongue reviewer.

Specific Comments

1. Introduction

R2: The scientific background of this article should be improved. Rather than associating "Incursions of high-energy particles from space, mainly solar wind, strongly interact with the Earth's magnetosphere" with the cause of auroral display, I would explicitly mention the coronal mass ejection with southward interplanetary magnetic field as a cause of auroral displays in low to mid magnetic latitude.

A: We have rewritten and enlarge the background section including specific references to coronal mass ejection as cause of low to mid aurora (LMLA) as follows: "Low and Mid latitude auroras (LMLAs) are usually associated with intense space weather events, frequently caused by coronal mass ejections (CME) (Gonzalez et al., 1994; Vázquez et al. 2006). This was the case of well studied extreme space weather events as those occurred on September 1770 (Hayakawa et al. 2017a); the Carrington event in August/September 1859 (Green and Boardsen, 2006; Green et al., 2006; Humble 2006; Tsurutani et al., 2003; Cliver and Dietrich, 2013; Hayakawa et al., 2019a); the storm on 1872 February (Hayakawa et al. 2018; Silverman, 2008); the extreme event on September 1909 (Hayakawa et al., 2019b); May 1921 (Hapgood, 2019; Silverman and Cliver, 2001; Love et al., 2019) or March 1989 (Allen et al., 1989) resulting in extreme magnetic disturbances and auroral displays at very low latitudes."

R2: I advice the authors to cite Gonzalez et al. (1994) and Daglis et al. (1999) for its references, rather than Vazquez et al. (2014).

A: References have been substituted as indicated.

Gonzalez, W. D., Joselyn, J. A, Kamide, Y., Kroehl, H. W., Rosoker, G., Tsuruani ,B. T. and Vasyliuna, V. M.: What is a geomagnetic storm?, J. Geophys. Res., 99, 5771-5792, doi.org/10.1029/93JA02867, 1994.

Daglis, I. A.: The terrestrial ring current: Origin, formation, and decay, Reviews of Geophysics, 37, 407-438, doi 10.1029/1999RG900009, 1999

R2: The space weather hazards are not only geomagnetically induced currents, but also satellite drags (Oliveira and Zesta, 2019) or atmospheric radiations (Dyer et al., 2018). These details should be cited with actual cases reports/predictions (Nakamura et al., 2018; Love et al., 2018; Boteler, 2019) and reviews (Pulkkinen et al., 2017; Ngwira and Pulkkinen, 2018; Riley et al., 2018; Oliveira et al., 2018).

A: Following the suggestion of the referee we have include some actual cases and mentioned explicitly some space weather hazards:

''It is important to note that extreme space weather events of these magnitude can provoke important impacts on our highly technological dependent society, especially in activities related with the aviation, the GPS signals, radio communication, and the electric power grid (Baker et al., 2008; Ridley et al., 2018). ''

R2: Given the magnetic latitude of Béziers (50.2° MLAT), I would consider this aurora not as "low-latitude aurora" but as "mid-latitude aurora". In comparison with auroral ovals during the extreme storms like the Carrington event (~30° MLAT), I consider that this extent is confined in mid magnetic latitude.

A: Thank you, for the comment we have considered the Rozier aurora as mid latitude, modifying the title and the text accordingly.

R2: The references on the Carrington event should be updated.

A: Thank you, the event of the 1859 described as: ''the Carrington event in August/September 1859 (Green and Boardsen, 2006; Green et al., 2006; Humble 2006; Tsurutani et al., 2003; Cliver and Dietrich, 2013; Hayakawa et al., 2019a); '' has the following references:

Green, J. L. and Boardsen, S.A.: Duration and extent of the great auroral storm of 1859, Adv. Space Res. 38, 130–135, 10.1016/j.asr.2005.08.054, 2006.

Green, J.L., Boardsen, S. A, Odenwald, S., Humble, J. and Pazamickas, K.A.: Eyewitness reports of the great auroral storm of 1859, Adv.Space Res. 38-2, 145-154, doi.org/10.1016/j.asr.2005.12.021, 2006.

Humble, J.: The solar events of August/September 1859 – Surviving Australian observations, Adv. Space Res. 38, 155–158, 10.1016/j.asr.2005.08.053, 2006.

Tsurutani, B. T., Gonzalez, W. D., Lakhina, G. S. and Alex, S.: The extreme magnetic storm of 1–2 September 1859, J. Geophys. Res., 108, 1268, doi:10.1029/2002JA009504, 2003.

Cliver, E. W. and Dietrich, W. F.: The 1859 space weather event revisited: limits of extreme activity, J. Space Weather Space Clim. 3, A31, doi: 10.1051/swsc/2013053, 2013.

Hayakawa, H., Ebihara, Y., Willis, D.M., Toriumi, S., Iju, T., Hattori, K., Wild, M. N., Oliveira, D. M., Ermolli, I., Ribeiro, J. R., Correia, A.P., Ribeiro, A. I. and Knipp, D. J: Temporal and Spatial Evolutions of a Large Sunspot Group and Great Auroral Storms Around the Carrington Event in 1859, Avd. Space Res, 17, 1553–1569. https://doi.org/10.1029/2019SW002269, 2019a.

R2: The reference of Green et al. (2014) is probably Green et al. (2006), as long as checking the NASA ADS database.

A: The referee is right, the reference has been amended.

R2: Three benchmark articles for this event should be cited in this context (Tsurutani et al., 2003; Cliver and Dietrich, 2013; Hayakawa et al., 2019a).

A: References have been added as indicated.

R2: Moreover, recent studies have located at least three rivaling storms with extremely low-latitude auroral visibility: 1872 Feb (Silverman, 2008; Hayakawa et al., 2018) and 1921 May (Silverman and Cliver, 2001; Hapgood, 2019; Love et al., 2019). These cases should be documented as well.

A: Thank you. The section has been updated as follows: "the storm on 1872 February (Hayakawa et al. 2018; Silverman, 2008); the extreme event on September 1909 (Hayakawa et al., 2019b); May 1921 (Hapgood, 2019; Silverman and Cliver, 2001; Love et al., 2019) or March 1989 (Allen et al., 1989) resulting in extreme magnetic disturbances and auroral displays at very low latitudes." Adding the quoted references:

Hayakawa, H., Ebihara, Y., Willis, D. M., Hattori, K., Giunta, A. S., Wild, M. N., Hayakawa, S., Toriumi, S.: The Great Space Weather Event during 1872 February Recorded in East Asia, The Astrophysical Journal, 862, 15. doi: 10.3847/1538-4357/aaca40, 2018.

Hayakawa, H., Ebihara, Y., Cliver, E. W., Hattori, K., Toriumi, S., Love, J. J., Umemura, N., Namekata, K., Sakaue, T., Takahashi, T., and Shibata, K.: The extreme space weather event in September 1909. Monthly Notices of the Royal Astronomical Society, 484, 3, 4083-4099. DOI: 10.1093/mnras/sty3196, 2019b.

Hapgood, M.: The Great Storm of May 1921: An Exemplar of a Dangerous Space Weather Event, Adv. Space Res., 17, 950–975. https://doi.org/10.1029/ 2019SW002195, 2019

Love, J. J., Hayakawa, H. and Clive, E. W.: Intensity and Impact of the New York Railroad Superstorm of May 1921, Avd. Space Res, 17, 1281–1292. doi.org/10.1029/2019SW002250, 2019.

Silverman, S.M. and Cliver, E.W.: Low-latitude auroras: the magnetic storm of 14 –15 May 1921, J. Atmos. Sol-Terr. Phys. 63, 523–535, doi.org/10.1016/S1364-6826(00)00174-7, 2001

Silverman, S.M.: Low-latitude auroras: The great aurora of 4 February 1872, J. Atmos. Sol.-Terr. Phys. 70, 1301- 1308, doi.org/10.1016/j.jastp.2008.03.012, 2008.

Allen, J., Frank, L., Sauer, H. and Reiff, P.: Effects of the March 1989 Solar Activity, EOS, 70, 1479-1488. doi: 10.1029/89EO004090, 1989.

R2: The usage of LLA as historical solar activity is another story. I would rephrase this as “Being footprints of solar eruptions, the mid-latitude aurorae (or low-latitude aurorae) are considered as proxies for the long-term solar variability”, citing several relevant articles such as Silverman (1992), Lockwood and Barnard (2015), Lockwood et al. (2016), Vázquez et al. (2016), and Hayakawa et al. (2017).

*A: The sentence has been re-phrased as follows: “Low and mid latitude auroras nights show an association with solar activity indices as sunspot records. This link has been observed during the telescopic era (**Silverman, 1992; Lockwood and Barnard, 2015; Lockwood et al., 2016**) but also in pre-telescopic era from the comparison with naked-eye sunspot reports (**Hayakawa et al. 2017a; Bekli and Chadou, 2019**). This relationship is due mainly to the highest frequency of LMLAs during the maximum and the decaying phase of the solar cycle (**Gonzalez et al., 1994**). Therefore, the mid-latitude aurorae, being footprints of solar CMEs, can be considered as proxies for the long-term solar activity. Nevertheless, LMLAs sometimes occurred in periods of low solar activity (**Silverman 2003; Willis et al. 2007; Vaquero et al., 2007 and 2013; Garcia and Dryer, 1987 and Hayakawa et al., 2020**). These auroras are called “sporadic auroras”. “*

and references have been added:

Silverman, S.M.: Secular variation of the aurora for the past 500 years, Rev. Geophys., 30, 333-351, doi.org/10.1029/92RG01571, 1992.

Lockwood, M., and Barnard, L.: An arch in the UK, Astronomy & Geophysics, 56, 4.25–4.30, doi.org/10.1093/astrogeo/atv132, 2015.

Lockwood, M., Owens, M.J., Barnard, L., Scot,t C.J., Usoskin, I.G. and Nevanlinna, H.: Tests of Sunspot Number Sequences: 2. Using Geomagnetic and Auroral Data, Sol. Phys., 291, 2811–2828, doi 10.1007/s11207-016-0913-2, 2016.

Hayakawa H., Tamazawa H., Ebihara Y., Miyahara H., Kawamura A. D., Aoyama T. and Isobe H.: Records of sunspots and aurora candidates in the Chinese official histories of the Yuán and Míng dynasties during 1261–1644, Publ. Astron. Soc. Jpn 69, 65, doi: 10.1093/pasj/psx045, 2017a.

Bekli ,M.R., and Chadou, I.: Analysis of pre-telescopic sunspots and auroras from 8th to 16th century. Adv. Space Res. 64, 1011-1018, 2019.

Gonzalez, W. D., Joselyn, J. A, Kamide, Y., Kroehl, H. W., Rosoker, G., Tsuruani ,B. T. and Vasyliuna, V. M.: What is a geomagnetic storm?, J. Geophys. Res., 99, 5771-5792, doi.org/10.1029/93JA02867, 1994.

Willis, D.M., Stephenson, F.R. and Fang H.: Sporadic aurorae observed in East Asia. Ann. Geophys., 25, 417-436, doi.org/10.5194/angeo-25-417-2007, 2007.

Vaquero, J.M., Trigo, R.M., Gallego, M.C.: Sporadic aurora from Spain. Earth Planets Space, 59, 49-51, doi.org/10.1186/BF03352061, 2007.

Vaquero, J.M., Gallego, M.C.and Domínguez-Castro, F.: A possible case of Sporadic Aurora in 1843 from Mexico. Geofísica Internacional 52, 87-92, 2013.

Garcia, H. A. and Dryer, M.: The Solar Flares of February 1986 and the Ensuing Intense Geomagnetic Storm, Sol. Phys. 109, 119-137, doi.org/10.1007/BF00167403, 1987.

Hayakawa, H., Ribeiro, P., Vaquero, J. M., Gallego, M. C., Knipp, D. J., Mekhaldi, F., Bhaskar, A., Oliveira, D. M., Notsu, Y., Carrasco, V. M. S., Caccavari, A., Veenadhari, B., Mukherjee S. and Ebihara Y.: The Extreme Space Weather Event in 1903 October/November: An Outburst from the Quiet Sun, Astrophys. J. Lett., DOI: 10.3847/2041-8213/ab6a18, 2020.

R2: Caveats must be noted here, however. Even when the solar activity is low, several great magnetic storms with significant auroral displays are reported as well (Garcia and Dryer, 1987; Hayakawa et al., 2020). This caveat should be clarified too.

A: Thank you. References have been added as indicated and the section has been updated as described in our previous answer.

2. Methodology

R2: It is nice to cite Rozier's portrait and personal detail in this article. However, citing them from wikisource or other online resources is not the best scientific practice. Please specify their original references in the publications and cite them accordingly. The reference clarifications are especially important as most of P2 of this manuscript is devoted to its explanation and the readers may wish to know more about him with appropriate references.

A: The Reference: Gutton, J.P. and Bonnet, J. C., Guton J. P. (Ed): Les Lyonnaises dans l'Histoire, Privat, 1991 has been substituted.

3. Analyses of the Observations

R2: The analyses seem sound but some improvements seem advised.

The description of ""a flash started from the end of the lower area…". This is a frequent structure of the aurorae (Vaquero & Vasquez, 2009)" may be flaming of auroral display (Störmer, 1955). If the description of "a main structure of two bands oriented east to west" means westward auroral motion, this sounds consistent to the westward traveling surge (Ebihara and Tanaka, 2015).

A: The section related to the Shape of the auroral event has been completely updated as follows:

"Shape: Related to the shape description, Rozier was very accurate. The main structure described by Rozier is : "it formed a zone, a phosphoric band…at a height of 3 feet....and finally it formed an angle of 60°…. above this first luminous zone a second [zone] of the same height was formed, but with 30° of extension only i.e. half of that of the lower zone. Between one and the other a void remained, the height of which matched that one of the two connected zones". This description may fit with the report of the auroral forms class without ray structure i.e. homogeneous arcs or uniform diffuse surface, and homogenous bands too (Störmer, 1955).

Nevertheless the beginning of the aurora could resemble some aspect of an auroral sub-storm expansion (Ebihara et al., 2017 and Stephenson et al., 2019) which is characterized by initial brightening of aurora, followed by a bulge expanding in all directions (Akasofu, 1964; Akasofu et al., 1965) "I noticed a luminous point…this luminous point acquired slowly [over *time] volume and intensity". Moreover, Rozier records some flaming during the event "in one or in the other zone I noticed irregularities, as well as on the edges of those big white clouds [i.e. general mass or bulge]. This edge was not homogeneously bright, although in the center presented uniform bright. In the time over which the zones moved Eastward…. a flash started from the end of the lower area [of the general mass or bulge]"."*

R2: The whitish auroral colour are explained with "the enhancement of the 630,0 nm [OI] emission caused by soft electrons (<100 eV) precipitating from the plasmasphere" in this manuscript. However, I suspect the whitish colour may be explained to the enhancement of the 557.7 nm of Oxygen with weak brightness or its mixture with other emissions as well (e.g., Ebihara et al., 2017; Stephenson et al., 2019). Rather than citing Abott and Juhl's statistics, it would be more straightforward to cite actual observational cases of whitish aurorae (See Section 6 of Stephenson et al., 2019).

A: The section has been updated as well as the references as follows:

"*Color: He carefully mentioned the color: "whitish color of phosphorus burning in the open air". As stated by Stephenson et al. 2019 at Low-Mid geomagnetic latitude, northern lights have generally higher probability to be observed if they are reddish, however in case of an auroral display without enough brightness, it tends to appear whitish to the human eye. In addition, such effect of the human eye is enhanced if the moon is also present in the sky as the eye cannot be "dark adapted". Moreover, the whitish auroral color may be explained with the enhancement of the 557.7 nm of Oxygen with weak brightness or due to the Oxygen mixture with other emissions as well (Ebihara et al., 2017; Stephenson et al., 2019). Examples of observation which confirm that LMLA are whitish in color during extreme space weather events are reported by Ebihara et al. 2017; Green and Boardsen, 2006; Hayakawa et al. 2017b and Willis et al.1996. Rozier observed a white aurora, this made the phenomena more unusual and increase the possibility of misinterpretation of the phenomenon by Rozier himself."*

R2: For the sunspot number analyses, the authors need to cite the data source "WDC SILSO" appropriately. Likewise, the authirs need to mention the WDC SILSO in the acknowledgment.

A: The reference has been corrected and quoted as required in the website i.e. SILSO, World Data Center - Sunspot Number and Long-term Solar Observations, Royal Observatory of Belgium, on-line Sunspot Number catalogue: http://www.sidc.be/SILSO/, 'year(s)-of-data'.

In the Acknowledgment we wrote: "Credits for the use of Sunspot data to the World Data Center SILSO, Royal Observatory of Belgium, Brussels."

R2: I would strongly recommend the authors to cite Clette et al. (2014) and Clette and Lefevre, 2016) for this dataset.

A: References added in the reference list and in the text as follows:

Clette, F. and Lefèvre, L.: The New Sunspot Number: Assembling All Corrections, Sol. Phys., 291, 2629-2651, doi 10.1007/s11207-016-1014-y, 2016.

Clette, F., Svalgaard, L., Vaquero, J. M. and Cliver, E. W.: Revisiting the Sunspot Number A 400-Year Perspective on the Solar Cycle, Space Sci. Rev.,186, 35–103, doi10.1007/s11214-014-0074-2, 2014.

R2: I suspect that the cause of this storm is probably better explained with the coronal mass ejections (see Gonzalez et al., 1994; Daglis et al., 1999) rather than the high-speed solar wind from the corona hole.

A: This was clarigied immediately in the backround and introduction: "Low and Mid latitude auroras (LMLAs) are usually associated with intense space weather events, frequently caused by coronal mass ejections (CME) (Gonzalez et al., 1994; Daglis, 1999; Vázquez et al. 2006). "

Conclusion

R2: The conclusion needs to be more developped to be an independent original article.

A: The conclusions have been rewritten as follows:

" We have found a record of an atmospheric phenomenon observed on 15 August 1780 in Beausejour, close to Béziers (43º 19′ N, 3º 13′ E), France, by the abbot Francois Rozier described as a "big white cloud ... whitish color of phosphorus burning in the open air". Rozier was not an astronomer and it is clear that he did not fully understand the phenomenon he was recording. Probably for this reason he recorded the event with minute details to later discuss it with other academicians of his time. Thanks to this accuracy, we have been able to analyse quantitative information and facts that contribute to confirm that Francois Rozier observed a Mid latitude aurora that night. The aurora was observed during the nautical and astronomical twilight, it was white, enough brilliant to not be overshined by the full moon which however was above the horizon in ESE direction. It showed two bands and some rays which could fit with the class of auroral forms of both homogeneous arcs/uniform diffuse surface, and homogenous bands. Its temporal evolution could also resemble an auroral sub-storm expansion.

This auroral event contributes to enlarge the geomagnetic knowledge of the late 18th century period in which the geomagnetic and the solar activity have high uncertainties due to few sunspot and LMLA observations reported from primary sources.

The Rozier record is a clear case of how, a scientist from a research field far from Astronomy or Meteorology in the 18th century, could record and publish descriptions on atmospheric phenomena that he did not fully understand but however he considered worth to be documented. These sources are very valuable because they report details of infrequent and/or partially unknown atmospheric phenomena. In this case the Rozier's report had contributes to enlarge the geomagnetic knowledge of a period with low information. "

Supplement

R2: It may be helpful to reproduce the French text here, as the authors stated "complete original French version is reported in the Supplementary Materials".

A: Both pages of the original text have been added in Figure 1. The sentence in the manuscript has been corrected consequently.

Minor Comments

R2: P1L12: The authors need to be consistent for the usage of Béziers or Bezier.

A: The text has been corrected using Béziers all times.

R2: By the ways, isn't the observational site Beauséjour? If this is the case, the coordinate should be N43°19′, E3°13′.

A: Corrected

R2: P1L20: disturbs => disturbances

A: The term has been amended as indicated.

R2: P1L22: Babylonians (Stephenson et al., 2004) => Assyrians and Babylonians (Stephenson et al., 2004; Hayakawa et al., 2016, 2019b)

A: Text has been integrated as required as well as references.

R2: P1L30: "require an accurate analysis to avoid possible misinterpretations" => Cite Kawamura et al. (2016), Usoskin et al. (2017), and Stephenson et al. (2019) here.

A: References have been added as required i.e.

Kawamura A.D., Hayakawa H., Tamazawa H., Miyahara H. and Isobe H.: Aurora candidates from the chronicle of Qíng dynasty in several degrees of relevance, Publ. Astron. Soc. Japan, 68, 79, doi: 10.1093/pasj/psw074, 2016.

Usoskin, I.G., Kovaltsov, G.A., Mishina, L.N., Sokoloff, D.D. and Vaquero, J.: An Optical Atmospheric Phenomenon Observed in 1670 over the City of Astrakhan Was Not a Mid-Latitude Aurora, Sol. Phys., 292, 15. DOI: 10.1007/s11207-016-1035-6, 2017.

Stephenson, F. R., Willis D. M., Hayakawa, H., Ebihara, Y., Scott, C. J., Wilkinson, J. Wild, M. N.: Do the Chinese Astronomical Records Dated AD 776 January 12/13 Describe an Auroral Display or a Lunar Halo? A Critical Re-examination, Sol. Phys. 294, 36, doi.org/10.1007/s11207-019-1425-7, 2019.

R2: P2: Please italicise the journal titles.

A: Journal titles have been italicized.

R2: P2L48: Béziers (Beauséjour) => Beauséjour in the suburb of Béziers

A: The sentence has been modified as indicated.

R2: P3L68: "reported below in English" => "reported below in our English translation"

A: The expression has been modified as indicated.

R2: P3L95: "proved" => "proven"

A: The error has been corrected.

R2: P3L104: "the measure of time of the French Hours that lasted until the French
Revolution in 1789" => Please cite a reference for this statement.

A: the text has been modified as follows:" Hour of Observation and sun depression angle: Rozier describes the starting (20:05) and ending (20:17) hour of his observation as local solar time (LST) i.e. the measure of local time as in use in the XVIII century. The pendulum clocks locally could be synchronized following the daily data reported in the Ephemerides with the time of the sunrise, midday and sunset published yearly (Jeaurat, 1780). "

The Ephemerides from the Observatory of Paris for the year of the observation of Rozier has been quoted: "*Jeaurat, E.S : Connoissance des Temps pour l`Année bissextile 1780, Publiée Par l`ordre de l`Académie Royale des Sciences, et calculée par M. Jeaurat, de la meme Académie. De l`Imprimerie Royale, Paris, 1780. »*

R2: P3L104: "These times correspond" => "Given its longitude, these time stamps correspond"

A: The sentence has been integrated as indicated.

R2: P3L105: "nautical twilight" => "astronomical twilight"

A: Done.

R2: P4L122-123: For auroral audibility, cite the review of Silverman and Tuan (1973).

A: Done. The section has been rewritten as follows:" Noise: Silverman and Tuan (1973) said that from observational evidence, the most likely sound accompany auroral observations could derive from discharges generated by aurorally associated electric fields. Rozier, although in his observation reported: "It appeared [to me] that these areas were a simple mass of steam, only charged by electricity, which it made them transparent and phosphoric". However, he concluded saying that: "for three different times, a flash, with almost null noise, started from the end of the lower area [i.e. the bulge] … [and again] when the light flashed …there was no blast". This absence of sound recorded by Rozier discard a possible misinterpretation with other noisy atmospheric phenomena." The reference has been added as required: Silverman, S.M. and Tuan, T.F.: Auroral Audibility, Ad. Geophys., 16,155-266, doi.org/10.1016/S0065-2687(08)60352-0, 1973.

R2: P5L124-128: For bright aurorae visible during night with the full moon, it would be advised to reinforce the existing discussions with actual observational cases cited in Stephenson et al. (2019) and Hattori et al. (2019).

*A: The section has been updated as follows:" Moon: whether or not an aurora is overshined by the moon depends on the lunar phase, the brightness of the aurora, and the angular distance between the moon and the sky position occupied by auroral emission (**Stephenson et al. 2019**). Rozier does not report any information about the moon. But the moon was in the sky that day. The moon, on 15 August 1780 was full moon and rose at 19:25 (UT) at an azimuth angle of 111.4° ESE direction, i.e. opposite respect the direction of observation of Rozier and close to the horizon. During the time Rozier observed the phenomenon, the moon was at azimuth angle 116.5° and elevation angle 3.4° (at 19:55 UT) while at the end of his observation it was at azimuth angle 118.5° and elevation angle 5.3° (at 20:07 UT) therefore always in the direction ESE. The short time of the observation suggests that although the aurora was highly bright because Rozier could record it with full moon in the sky **(Stephenson et al., 2019; Hattori et al., 2019**), however because of the moon rise above the horizon the light conditions could hinder the visibility of the aurora as well as the presence of tropospheric clouds. In literature several auroral observations are reported during full moon e.g. those observed on the 18 February and on 12 November 1837 (**Olmsted, 1837; Snow, 1842**), those reported by Martin, 1847 and Glaisher, 1847 on October 24 of that year, and the event observed on 4 September 1908 described by **Barnard, 1910**."*

Reference added in the reference list:

Stephenson, F. R., Willis D. M., Hayakawa, H., Ebihara, Y., Scott, C. J., Wilkinson, J. Wild, M. N.: Do the Chinese Astronomical Records Dated AD 776 January 12/13 Describe an Auroral Display or a Lunar Halo? A Critical Re-examination, Sol. Phys. 294, 36, doi.org/10.1007/s11207-019-1425-7, 2019.

Hattori, K., Hayakawa, H. and Ebihara, Y.: Occurrence of Great Magnetic Storms on 6–8 March 1582, Mon. Not. R. Astron. Soc., 487, 3550–3559, doi.org/10.1093/mnras/stz1401, 2019.

Olmsted, D.: Observations on the aurora borealis on Jan. 25, 1837 Am. J. Sci. Arts 32, 176, 1837.

Snow, R.: Observations of the Aurora Borealis. From September 1834 to September 1839, Moyes & Barclay, London,1842.

Barnard, E.E.: Observations of the aurora, made at the Yerkes Observatory, 1902 – 1909. Astrophys. J. 31, 208, 1910.

R2: P5L137: "15th august 1780" => "15 August 1780".

A: The date has been corrected.

R2: P5L143: "is" => "it is"

A: The subject has been added.

R2: P6L157: "decrease phase" => "declining phase"

A: The expression has been modified as indicated.

R2: P6L158: "2-years delayed respect the peak of the highest solar activity" => "2-years after the maximum"

A: The sentence has been modified as required.

R2: P6L160: Cite Lefevre et al. (2016) here.

A: The reference has been added: Lefèvre, L.: Detailed Analysis of Solar Data Related to Historical Extreme Geomagnetic Storms: 1868 – 2010, Sol. Phys., 291, 1483-1531. DOI: 10.1007/s11207-016-0892-3, 2016.

R2: P6L160: "few solar observation" => "few sunspot observations"

A: The word has been substituted as indicated.

R2: P6L162: "very welcomed" => "useful" or "informative"

A: The word has been substituted as indicated

R2: P6L164: "this solar observation" => maybe "the nearest solar observation"?

A: Done

R2: P6L166: "This is 48 days without sunspot information" => "It means this event occurred in an interval without sunspot data for 48 days".

A: The sentence has been modified as indicated.

R2: Figure 1: The two figures are overlapped. They should be separated at least.

A: Both pages of the document are reported in figure 1 instead of Fig. 1a and Fig 1b.

R2: The data source of the photograph should be addressed not with the URL but with shelf mark in the Library of Congress Prints and Photographs Division Washington.

A: Done

R2 : Figure 3: Cite Clette et al. (2014) and Clette and Lefevre (2016) here.

A: References have been added:

Clette, F. and Lefèvre, L.: The New Sunspot Number: Assembling All Corrections, Sol. Phys., 291, 2629-2651, doi 10.1007/s11207-016-1014-y, 2016.

Clette, F., Svalgaard, L., Vaquero, J. M. and Cliver, E. W.: Revisiting the Sunspot Number A 400-Year Perspective on the Solar Cycle, Space Sci. Rev.,186, 35–103, doi10.1007/s11214-014-0074-2, 2014.

R2. Figure 4: Cite Dominguez-Castro et al. (2016) and Vaquero et al. (2016) here.

A: References have been added:

Domínguez-Castro, F., Vaquero, J.M., Bertolin, C., Gallego, M. C., De la Guia, C. and Camuffo, D. : Aurorae observed by Giuseppe Toaldo in Padua (1766-1797), J. Space Weather Spac., 6, A21, doi.org/10.1051/swsc/2016016, 2016.

Vaquero, J.M., Svalgaard, L., Carrasco, V.M.S., Clette, F., Lefèvre, L., Gallego, M.C., Arlt, R., Aparicio, A.J.P., Richard, J-G. and Howe, R.: A revised collection of sunspot group numbers. Sol. Phys. 291, 3061-3074, 10.1007/s11207-016-0982-2, 2016.

An Early Mid Latitude Aurora Observed by Rozier (Béziers, 1780)

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Abstract. Aurorae Observations are an uncommon phenomenon at low and mid latitudes that, at the end of the 18th century was not well known and understood. Low and Mid geomagnetic latitude Aurorae observations provide information about episodes of intense solar storms associated with flares and outstanding coronal mass ejection (CME) and on the variation of the geomagnetic field. However, for many observers at mid and low latitude, the features of a northern light were unknown, so they could easily report it as a phenomenon without explanation. In this work, we found that an earlier Mid geomagnetic latitude aurora was observed in Beausejour, close to Béziers (43º 19′ N, 3º 13′ E), France, by the abbot Francois Rozier. He was a meticulous botanist, doctor and agronomist with special interest in atmospheric phenomena. On 15 August 1780, from 19:55 to 20:07 (Universal Time), Francois Rozier observed a "phosphoric cloud". A careful analysis of the report points out that he was reporting an auroral event. The recovery of auroral events at low and mid latitude during the 1780's is very useful to shed light to the solar activity during this period because there are few records of sunspot observations.

1 Background and Introduction

Incursions of high-energy particles from space, mainly solar wind, strongly interact with the Earth's magnetosphere, causing ionization and excitation of atmospheric gases and auroral emissions (Brekke, 2013; Gonzalez et al., 1994). The aurora borealis is a spectacular phenomenon that have been recorded from the Assyrians and Babylonians (Stephenson et al., 2004; Hayakawa et al. 2016; Hayakawa et al. 2019c) till nowadays. However, it is not until 1733 when Mairan (1733) suggested that the aurora could be caused by the solar atmosphere (Krivsky, 1984).

Low and Mid latitude auroras (LMLAs) are usually associated with intense space weather events, frequently caused by coronal mass ejections (CME) (Gonzalez et al., 1994; Daglis, 1999; Vázquez et al. 2006). This was the case of well studied extreme space weather events as those occurred on September 1770 (Hayakawa et al. 2017a); the Carrington event in August/September 1859 (Green and Boardsen, 2006; Green et al., 2006; Humble 2006; Tsurutani et al., 2003; Cliver and Dietrich, 2013; Hayakawa et al., 2019a); the storm on 1872 February (Hayakawa et al. 2018; Silverman, 2008); the extreme event on September 1909 (Hayakawa et al., 2019b); May 1921 (Hapgood, 2019; Silverman and Cliver, 2001; Love et al., 2019) or March 1989 (Allen et al., 1989) resulting in extreme magnetic disturbances and auroral displays at very low latitudes. It is important to note that extreme space weather events of these magnitude can provoke important impacts on our highly technological dependent society, especially in activities related with the aviation, the GPS signals, radio communication, and the electric power grid (Baker et al., 2008; Ridley et al., 2018).

Low and mid latitude auroras nights show an association with solar activity indices as sunspot records. This link has been observed during the telescopic era (Silverman, 1992; Lockwood and Barnard, 2015; Lockwood et al., 2016) but also in pre-telescopic era from the comparison with naked-eye sunspot reports (Hayakawa et al. 2017a; Bekli and Chadou, 2019). This relationship is due mainly to the highest frequency of LMLAs during the maximum and the decaying phase of the solar cycle (Gonzalez et al., 1994). Therefore, the mid-latitude aurorae, being footprints of solar CMEs, can be considered as proxies for the long-term solar activity. Nevertheless, LMLAs sometimes occurred in periods of low solar activity (Silverman 2003; Willis et al. 2007; Vaquero et al., 2007 and 2013; Garcia and Dryer, 1987 and Hayakawa et al., 2020). These auroras are called "sporadic auroras".

Auroral catalogues are important tool to understand the long-term interaction among the solar activity and the Earth's magnetosphere (Legrand and Simon 1987, Silverman S.M. 1992). In the last centuries many auroral catalogues have been developed e.g. Mairan (1733), Lovering (1866), Fritz (1873), Angot (1897), Tromholt (1902), Link (1962, 1964), Krivsky & Pejml (1988), Loysha et al. (1989) or Ordaz (2010). LMLAs, although rare, are recorded in these catalogues by professional and non-professional observers. During the 18th century, in Europe, there were some professional observers who were familiar with the phenomenon and who recorded auroras systematically e.g. Francisco Salvà (Barcelona, Spain) (Vaquero et al., 2010) and Giuseppe Toaldo (Padova, Italy) (Domínguez-Castro et al., 2016). Nevertheless, there were many sporadic observers that also recorded LMLAs unknowingly, cataloging them as strange and inexplicable phenomena. These sporadic reports are important to generate and extend LMLAs catalogues but require an accurate analysis to avoid possible misinterpretations (Kawamura et al., 2016; Usoskin et al., 2017; Stephenson et al., 2019). Here, we analyzed an observation made by the Abbot Francois Rozier in 1780 with enough details and quantifiable information to understand if he observed a LMLA or a different phenomenon.

2 Methodology

2.1. The Observer

Jean-Baptiste François Rozier, (Lione, 23 January 1734 - Lione, 29 September 1793) (Fig. 1a) (Gutton and Bonnet, 1991) was a professor of Botanic and Medicine at the University of Lione that after studying at the Jesuit college at Villefranche-sur-Saône entered the the Saint-Irénée seminary in Lyon. In 1771 Rozier moved to Paris to edit the Journal de Physique et d' Histoire Naturelle founded by Jacques Gautier d' Agoty; after becoming the journal owner he renamed it as *Journal d' Observations sur la Physique, l' Histoire Naturelle et sur les Arts et Métier*s and later as the *Journal de Physique* where the original versions of many fundamental memoirs appeared (McKie, 1957). Rozier maintained the journal up to 1779 when he devoted himself to the writing of the *Cours d' agriculture* (see below) a periodical that was edited by his nephew, the mineralogist and priest Jean-André Mongez (21 November 1750 – May 1788). In 1779 he became prior of the abbey at Nanteuil-le-Haudouin (between Paris and Reims), while in July 1780 Rozier bought an estate close in Beauséjour, in the suburb of Béziers (43°19′ N, 3°13′ E), Southern France (domaine de Beauséjour) to install his own model farm (1781). Here he could edit his *Cours Complet d' Agriculture Théorique et Pratiqueou Dictionnaire Reisonné et Universel d' Agriculture* (twelve volumes in form of a dictionary, of which nine were by Rozier himself, 1781–1800, and the last two were published after his death). Finally, he sold the property and in 1786 moved to Lyon where he accepted a position as Director of the School of Agriculture and of the Pépinière (plant nursery) de la Province in 1788. Finally, he became constitutional curate of Sainte-Polycarpe parish in Lyon and was killed during the siege of the town the night between the 28th and 29th of September 1793 (French Revolution).

Rozier was a member of the Académie de Lyon and thanks to his activity as editor of scientific journals was in contact with the most famous scientists and intellectuals of his times. He devoted his life to the observation of botanical or agricultural biological, chemical, physical and meteorological phenomena (e.g. temperature, atmospheric pressure observations with barometers of different diameters or state of the sky as thunders` observations).

2.2. The Documentary Source and the Observation description

The observation was described in the "*Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce*" tome XVIII under the title "*Observation sur une Nuée rendue phosphorique par une surabondance de l'électricité, vue de Beauséjour près de Béziers, le 15 Août* " [About a cloud rendered phosphoric by an overabundance of electricity observed at Béziers the 15th of August] (Rozier, 1781) (Fig. 1b). The most important fragments of the observation are reported below in our English translation, while the complete original French version is reported in Figure 1b.

"*The closer the night approached, the more the clouds were pushed and accumulated towards the great chain of mountains of the third order that cross the low-Languedoc from east to west... At 20:05 it was completely night. It was at this moment that, examining the direction and the effects of the flashes, I noticed behind the slope of the hill, which on one side blocks the view from my house, a bright spot. This light did not look like that of a candle seen from afar, nor that which spreads from a forest or grass when they are set on fire. It seemed to me to have the whitish color of phosphorus burning in the open air, or rather of that of mercury stirred in a tube without air. This bright spot gradually acquired volume and intensity. It imperceptibly formed an area, a phosphoric band that appeared to my eyes at a height of 3 feet: and starting from the top of the hill almost to Béziers, this area seemed to form the base of a 60° angle, whose summit responded to my eye.*

On this first luminous area, a second one of the same height formed, and it had only 30° of extension [width], or half of that of the lower area. Between them remained a void whose height equaled that one of the two areas considered separately.

Even if these two zones followed a horizontal direction, it is not to believed that their line of demarcation followed exactly a straight line. We noticed on both some irregularities, roughly as on the edges of that big white cloud, storm forerunners, and these edges were not all equally bright even if the center of the zones showed a uniform light.

During the period of time when these areas were moving eastward, the lightning and thunder noise were more rapid; finally, at three different times, a flash started from the end of the lower area. But an object worthy of note is that the noise following these flashes, if there was one, was weak and I would dare to say almost null because I could not distinguish it from the *noise of the thunder that was starting from the upper region and from a greater distance. Every flash, launched by the general mass, made me clearly appreciate the vines, the crops, the top and the sinuosity of the small mountains located in front of the big chain.*

That light helped me to understand that the areas were closer to me and did not belong to the mass of clouds pushed by the winds towards the mountain.

This phenomenon was shown from 20.05 until 20.17. In this instant a blow of wind from the south changed the direction of the clouds, bringing them closer to the big mountain chain, and the storm moved away from Beziers.

It would seem that these areas were a simple mass of vapors, only charged by electricity, which made them transparent and phosphoric. It is proven by the fact that three times the flash disappeared and the trail of light left by the flash appeared to be more than twice the diameter of normal flashes. The [apparent] proximity of the objects could, it is true, be due to these optical effects.

I am led to believe that these areas were detached entities [bodies] and that they did not belong to the mass of the other clouds because the mountains were visible behind them when the flash departed from the big mass; finally, when the flash started from these areas, there was no blast.

I don't know if such a phenomenon has been observed elsewhere; but I never read anything that can be compared to it."

3 Analysis of the Observation

Hour of Observation and sun depression angle: Rozier describes the starting (20:05) and ending (20:17) hour of his observation as local solar time (LST) i.e. the measure of local time as in use in the XVIII century. The pendulum clocks locally could be synchronized following the daily data reported in the Ephemerides with the time of the sunrise, midday and sunset published yearly (Jeaurat, 1780). Given its longitude, these times correspond to 19:55 and 20:07 in Universal Time (UT) respectively. At these times the solar depression angle was 11.5° and 13.3° respectively. Therefore, although Rozier described the observational conditions as if it was "completely night", however the observation started during the nautical twilight and concluded in the astronomical twilight. The calculation of the solar depression angle for the geographical coordinates in Béziers and the day of the observation has been performed using the HORIZONS Web-interface of the American National Aeronautics and Space Administration (NASA) (https://ssd.jpl.nasa.gov/horizons.cgi?s_type=1#top).

Shape: Related to the shape description, Rozier was very accurate. The main structure described by Rozier is : "*it formed a zone, a phosphoric band…at a height of 3 feet....and finally it formed an angle of 60°…. above this first luminous zone a second* [zone] *of the same height was formed, but with 30° of extension only i.e. half of that of the lower zone. Between one and the other a void remained, the height of which matched that one of the two connected zones*". This description may fit with the report of the auroral forms class without ray structure i.e. homogeneous arcs or uniform diffuse surface, and homogenous bands too (Störmer, 1955).

Nevertheless the beginning of the aurora could resemble some aspect of an auroral sub-storm expansion (Ebihara et al., 2017 and Stephenson et al., 2019) which is characterized by initial brightening of aurora, followed by a bulge expanding in all directions (Akasofu, 1964; Akasofu et al., 1965) "*I noticed a luminous point…this luminous point acquired slowly* [over time] *volume and intensity"*. Moreover, Rozier records some flaming during the event "*in one or in the other zone I noticed irregularities, as well as on the edges of those big white clouds* [i.e. general mass or bulge]. *This edge was not homogeneously bright, although in the center presented uniform bright. In the time over which the zones moved Eastward…. a flash started from the end of the lower area* [of the general mass or bulge]".

Color: He carefully mentioned the color: "*whitish color of phosphorus burning in the open air*". As stated by Stephenson et al. 2019 at Low-Mid geomagnetic latitude, northern lights have generally higher probability to be observed if they are reddish, however in case of an auroral display without enough brightness, it tends to appear whitish to the human eye. In addition, such effect of the human eye is enhanced if the moon is also present in the sky as the eye cannot be "dark adapted". Moreover, the whitish auroral color may be explained with the enhancement of the 557.7 nm of Oxygen with weak brightness or due to the Oxygen mixture with other emissions as well (Ebihara et al., 2017; Stephenson et al., 2019). Examples of observation which confirm that LMLA are whitish in color during extreme space weather events are reported by Ebihara et al. 2017; Green and Boardsen, 2006; Hayakawa et al. 2017b and Willis et al.1996. Rozier observed a white aurora, this made the phenomena more unusual and increase the possibility of misinterpretation of the phenomenon by Rozier himself.

Noise: Silverman and Tuan (1973) said that from observational evidence, the most likely sound accompany auroral observations could derive from discharges generated by aurorally associated electric fields. Rozier, although in his observation reported: *"It appeared* [to me] *that these areas were a simple mass of steam, only charged by electricity, which it made them transparent and phosphoric"*. However, he concluded saying that: *"for three different times, a flash, with almost null noise, started from the end of the lower area* [i.e. the bulge] … [and again] *when the light flashed …there was no blast"*. This absence of sound recorded by Rozier discard a possible misinterpretation with other noisy atmospheric phenomena.

Moon: whether or not an aurora is overshined by the moon depends on the lunar phase, the brightness of the aurora, and the angular distance between the moon and the sky position occupied by auroral emission (Stephenson et al. 2019). Rozier does not report any information about the moon. But the moon was in the sky that day. The moon, on 15 August 1780 was full moon and rose at 19:25 (UT) at an azimuth angle of 111.4° ESE direction, i.e. opposite respect the direction of observation of Rozier and close to the horizon. During the time Rozier observed the phenomenon, the moon was at azimuth angle 116.5° and elevation angle 3.4° (at 19:55 UT) while at the end of his observation it was at azimuth angle 118.5° and elevation angle 5.3° (at 20:07 UT) therefore always in the direction ESE. The short time of the observation suggests that although the aurora was highly bright because Rozier could record it with full moon in the sky (Stephenson et al., 2019; Hattori et al., 2019), however because of the moon rise above the horizon the light conditions could hinder the visibility of the aurora as well as the presence of tropospheric clouds. In literature several auroral observations are reported during full moon e.g. those observed on the 18 February and on 12 November 1837 (Olmsted, 1837; Snow, 1842), those reported by Martin, 1847 and Glaisher, 1847 on October 24 of that year, and the event observed on 4 September 1908 described by Barnard, 1910.

Geomagnetic latitude: We have calculated the temporal evolution of the geomagnetic latitude in Beziers for the night of the observation using the geomagnetic model gufm1 (Jakson et al., 2000). The geomagnetic latitude, φ equals to 50,18°N is obtained by equation (2) in the hypothesis of a dipolar configuration for the geomagnetic field.

$$\boldsymbol{\varphi} = \frac{\tan I}{2} \qquad (2)$$

where I is the magnetic inclination obtained from the gufm1 model for the year 1780. This implies that the aurora is in the lower limit of the mid-latitude aurora or at the border for being defined LLA as this threshold often in literature is around 50,00°N of geomagnetic latitude.

4 Discussion

In the previous section we have verified that Rozier observed an aurora the night of the 15 August 1780. According with the Angot catalogue (Angot, 1897) in this night the aurora was also observed at Ratisbon (Germany, 49º 01’ N, 12° 05’ E), 5.5° further north than Beziers. The Angot catalogue has been extensively used on the reconstruction of auroral nights and as a proxy of the long-term geomagnetic variability. Nevertheless, it is important to note that Angot (1897) is a secondary source (the author was no witness of the facts he describes) and does not provide information on the primary sources he consulted for the elaboration of the catalogue. Secondary sources must be used carefully because can include errors due to the transcription or interpretation of the primary source. For this reason, it is valuable to found primary sources that corroborate the information provided by Angot, specially during the nights in which Angot recorded an event in a single location, as the night of 15 August 1780.

In addition, magnetic indexes are not available in 1780. The Ak index is in fact available since 1844 (Nevanlinna & Kataja, 1993), the aa index since 1868 (Mayaud, 1980) and the geomagnetic IDV index (Svalgaard & Cliver, 2010) is available since 1835. For this reason, LMLAs catalogues and sunspot number are used here as proxies of the geomagnetic activity at Rozier’s times.

First the aurorae catalogue at comparable latitudes have been analyzed. Then, they were compared with two existing coeval series of auroras homogeneously recorded at low latitude by trained observers as Toaldo (1766-1797) (Padova, Italy 45º 24’ N, 11º 52’ E) (Domínguez-Castro et al., 2016) and Salvà (1780-1825) (Barcelona, Spain 41º 23’ N, 2º 10’ E) (Vaquero et al, 2010). For differentiation purpose, the additional series of auroras observed by Thomas Hughes from Stroud, United Kingdom (mid-latitude 51,75°N, 2,22°W) (Giles, 2005) has been also reported. Figure 2 shows the Toaldo, Salva and

Hughes yearly total observations of auroras and the geomagnetic latitude respectively in Padua, Barcelona, Stroud and Beziers over the common 1766-1800 period. The Rozier's observation was close to the maximum LLA observed by Toaldo in Padova (1779). Nevertheless, no aurora was recorded by Salvà at Barcelona during 1780. At higher latitudes (Stroud) Hughes recorded a mean low activity of auroras for that year.

Figure 3 shows the sunspot number during the period 1766-1800. Rozier´s observation was in the declining phase of the solar cycle 3, 2-years after the maximum. This is a good moment to see LMAA because long-lived coronal holes - source of high ionized particles in the solar wind - occur more frequently in the declining phase of the sunspot cycle (Verbanac et al., 2011; Lefèvre et al., 2016). It is important to note that the Rozier's observation occurred in a period with few sunspot records. As we can see in Figure 4 the solar observations during the 1780`s are rare, frequently below the 30 observations per year. For this reason, any contribution to the knowledge of the geomagnetic activity in this period is very beneficial.

Figure 4 shows at monthly resolution the solar activity and the auroras recorded in Padova from August 1779 to August 1781. We can see that no aurora was observed during August and only one solar observation was recorded in this month. The nearest solar observation was the 30th of August when J.C. Staudach report 4 groups in the solar disk. The previous observation was done by P. Zeno at 12th of July recording one group (Vaquero et al., 2016). It means this event occurred in an interval without sunspots data for 48 days.

Conclusions

We have found a record of an atmospheric phenomenon observed on 15 August 1780 in Beausejour, close to Béziers (43º 19′ N, 3º 13′ E), France, by the abbot Francois Rozier described as a "*big white cloud … whitish color of phosphorus burning in the open air*". Rozier was not an astronomer and it is clear that he did not fully understand the phenomenon he was recording. Probably for this reason he recorded the event with minute details to later discuss it with other academicians of his time. Thanks to this accuracy, we have been able to analyse quantitative information and facts that contribute to confirm that Francois Rozier observed a Mid latitude aurora that night. The aurora was observed during the nautical and astronomical twilight, it was white, enough brilliant to not be overshined by the full moon which however was above the horizon in ESE direction. It showed two bands and some rays which could fit with the class of auroral forms of both homogeneous arcs/uniform diffuse surface, and homogenous bands. Its temporal evolution could also resemble an auroral sub-storm expansion.

This auroral event contributes to enlarge the geomagnetic knowledge of the late 18th century period in which the geomagnetic and the solar activity have high uncertainties due to few sunspot and LMLA observations reported from primary sources.

The Rozier record is a clear case of how, a scientist from a research field far from Astronomy or Meteorology in the 18th century, could record and publish descriptions on atmospheric phenomena that he did not fully understand but however he considered worth to be documented. These sources are very valuable because they report details of infrequent and/or partially unknown atmospheric phenomena. In this case the Rozier's report had contributes to enlarge the geomagnetic knowledge of a period with low information.

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Authors contributions

C. Bertolin conceived the study, performed the analysis and drafted the manuscript with F. Dominguez-Castro, who wrote the final manuscript.

L. de Ferri translated the original data and conducted the historical research used in the study as well as contributed to scientific discussion of the article together with C. Bertolin and F. Dominguez-Castro.

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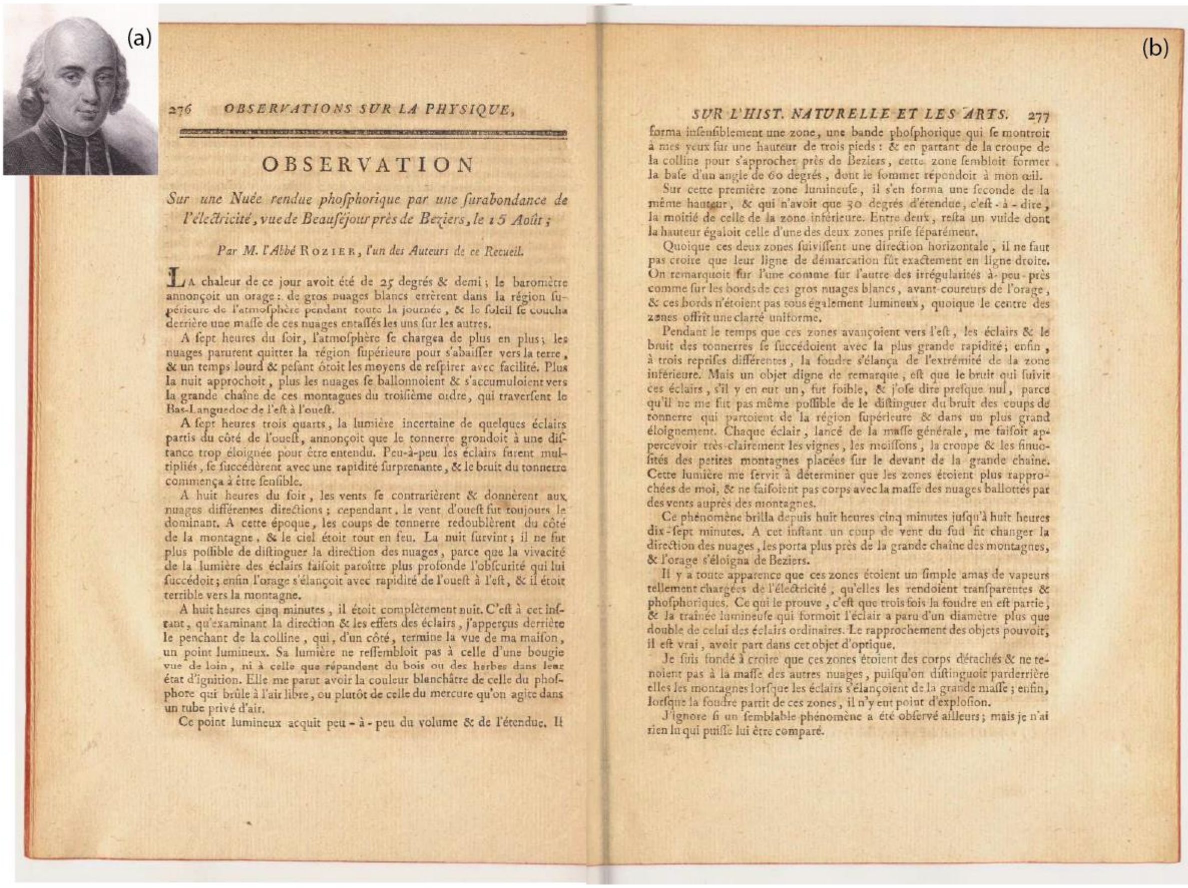

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OBSERVATION

Sur une Nuée rendue phofphorique par une furabondance de l'électricité, vue de Beaufèjour près de Beziers, le 15 Août;

Par M. l'Abbé ROZIER, *l'un des Auteurs de ce Recueil.*

LA chaleur de ce jour avoit été de 25 degrés & demi; le baromètre annonçoit un orage: de gros nuages blancs errèrent dans la région fupérieure de l'atmofphère pendant toute la journée, & le foleil fe coucha derrière une maffe de ces nuages entaffés les uns fur les autres.

A fept heures du foir, l'atmofphère fe chargea de plus en plus; les nuages parurent quitter la région fupérieure pour s'abaiffer vers la terre, & un temps lourd & pefant ôtoit les moyens de refpirer avec facilité. Plus la nuit approchoit, plus les nuages fe ballonnoient & s'accumuloient vers la grande chaîne de ces montagnes du troifième ordre, qui traverfent le Bas-Languedoc de l'eft à l'oueft.

A fept heures trois quarts, la lumière incertaine de quelques éclairs partis du côté de l'oueft, annonçoit que le tonnerre grondoit à une diftance trop éloignée pour être entendu. Peu-à-peu les éclairs furent multipliés, fe fuccédèrent avec une rapidité furprenante, & le bruit du tonnerre commença à être fenfible.

A huit heures du foir, les vents fe contrarièrent & donnèrent aux nuages différentes directions; cependant, le vent d'oueft fut toujours le dominant. A cette époque, les coups de tonnerre redoublèrent du côté de la montagne, & le ciel étoit tout en feu. La nuit furvint; il ne fut plus poffible de diftinguer la direction des nuages, parce que la vivacité de la lumière des éclairs faifoit paroître plus profonde l'obfcurité qui lui fuccédoit; enfin l'orage s'élançoit avec rapidité de l'oueft à l'eft, & il étoit terrible vers la montagne.

A huit heures cinq minutes, il étoit complètement nuit. C'eft à cet inftant, qu'examinant la direction & les effets des éclairs, j'apperçus derrière le penchant de la colline, qui, d'un côté, termine la vue de ma maifon, un point lumineux. Sa lumière ne reffembloit pas à celle d'une bougie vue de loin, ni à celle que répandent du bois ou des herbes dans leur état d'ignition. Elle me parut avoir la couleur blanchâtre de celle du phofphore qui brûle à l'air libre, ou plutôt de celle du mercure qu'on agite dans un tube privé d'air.

Ce point lumineux acquit peu-à-peu du volume & de l'étendue. Il

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forma infenfiblement une zone, une bande phofphorique qui fe montroit à mes yeux fur une hauteur de trois pieds: & en partant de la croupe de la colline pour s'approcher près de Beziers, cette zone fembloit former la bafe d'un angle de 60 degrés, dont le fommet répondoit à mon œil.

Sur cette première zone lumineufe, il s'en forma une feconde de la même hauteur, & qui n'avoit que 30 degrés d'étendue, c'eft-à-dire, la moitié de celle de la zone inférieure. Entre deux, refta un vuide dont la hauteur égaloit celle d'une des deux zones prife féparément.

Quoique ces deux zones fuiviffent une direction horizontale, il ne faut pas croire que leur ligne de démarcation fût exactement en ligne droite. On remarquoit fur l'une comme fur l'autre des irrégularités à-peu-près comme fur les bords de ces gros nuages blancs, avant-coureurs de l'orage, & ces bords n'étoient pas tous également lumineux, quoique le centre des zones offrît une clarté uniforme.

Pendant le temps que ces zones avançoient vers l'eft, les éclairs & le bruit des tonnerres fe fuccédoient avec la plus grande rapidité; enfin, à trois reprifes différentes, la foudre s'élança de l'extrémité de la zone inférieure. Mais un objet digne de remarque, eft que le bruit qui fuivit ces éclairs, s'il y en eut un, fut foible, & j'ofe dire prefque nul, parce qu'il ne me fut pas même poffible de le diftinguer du bruit des coups de tonnerre qui partoient de la région fupérieure & dans un plus grand éloignement. Chaque éclair, lancé de la maffe générale, me faifoit appercevoir très-clairement les vignes, les moiffons, la croupe & les finuofités des petites montagnes placées fur le devant de la grande chaîne. Cette lumière me fervit à déterminer que les zones étoient plus rapprochées de moi, & ne faifoient pas corps avec la maffe des nuages ballottés par des vents auprès des montagnes.

Ce phénomène brilla depuis huit heures cinq minutes jufqu'à huit heures dix-fept minutes. A cet inftant un coup de vent du fud fit changer la direction des nuages, les porta plus près de la grande chaîne des montagnes, & l'orage s'éloigna de Beziers.

Il y a toute apparence que ces zones étoient un fimple amas de vapeurs tellement chargées de l'électricité, qu'elles les rendoient tranfparentes & phofphoriques. Ce qui le prouve, c'eft que trois fois la foudre en eft partie, & la traînée lumineufe qui formoit l'éclair a paru d'un diamètre plus que double de celui des éclairs ordinaires. Le rapprochement des objets pouvoit, il eft vrai, avoir part dans cet objet d'optique.

Je fuis fondé à croire que ces zones étoient des corps détachés & ne tenoient pas à la maffe des autres nuages, puifqu'on diftinguoit parderrière elles les montagnes lorfque les éclairs s'élançoient de la grande maffe; enfin, lorfque la foudre partit de ces zones, il n'y eut point d'explofion.

J'ignore fi un femblable phénomène a été obfervé ailleurs; mais je n'ai rien lu qui puiffe lui être comparé.

Figure 1: (a) Photographic portrait of Abbot Francois Rozier (photo in public domain) Library of Congress Prints and Photographs Division Washington. (b) The two printed pages reporting the aurora observation made by Abbot Francois Rozier, on 15 August 1780 in Beziers, France (Rozier, 1781).

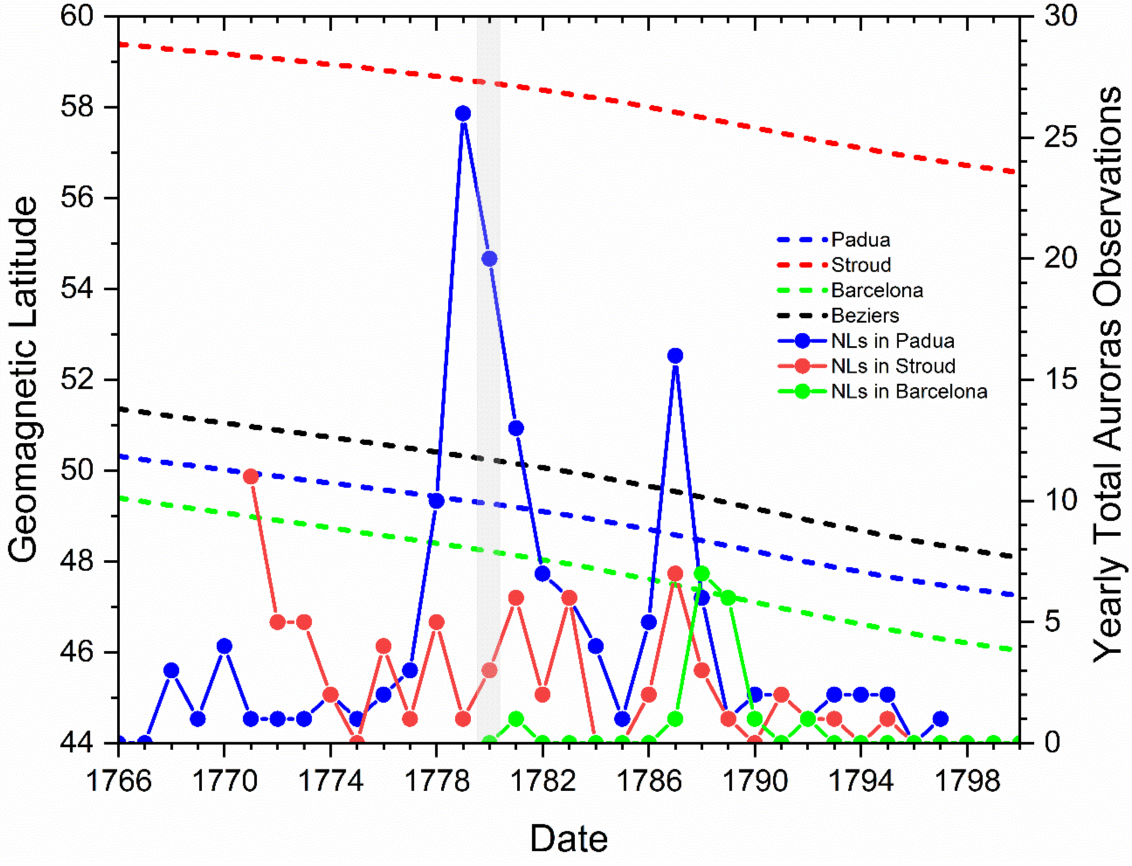


Figure 2: Geomagnetic Latitude variations for Padua, Barcelona Stroud and Beziers and yearly total auroras recorded in these places by Toaldo, Salva and Hughes. The grey column remarks the year of the Rozier's auroral observation 1780.

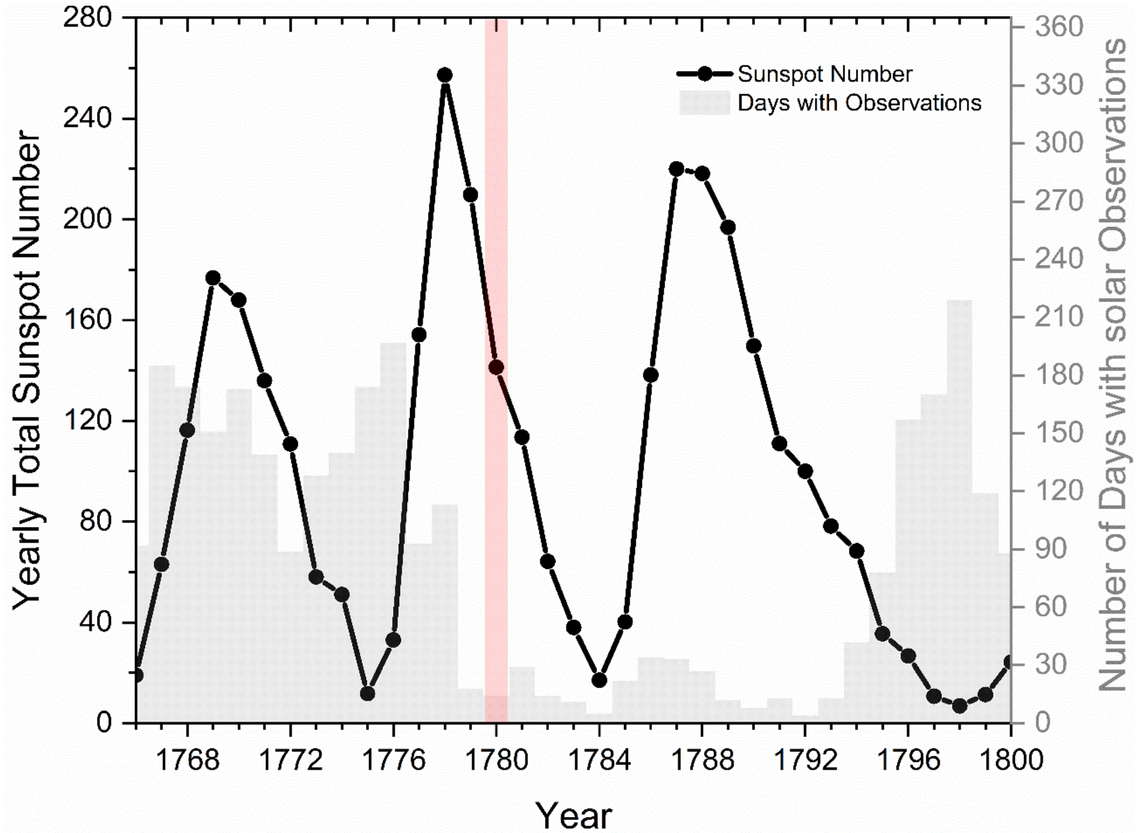
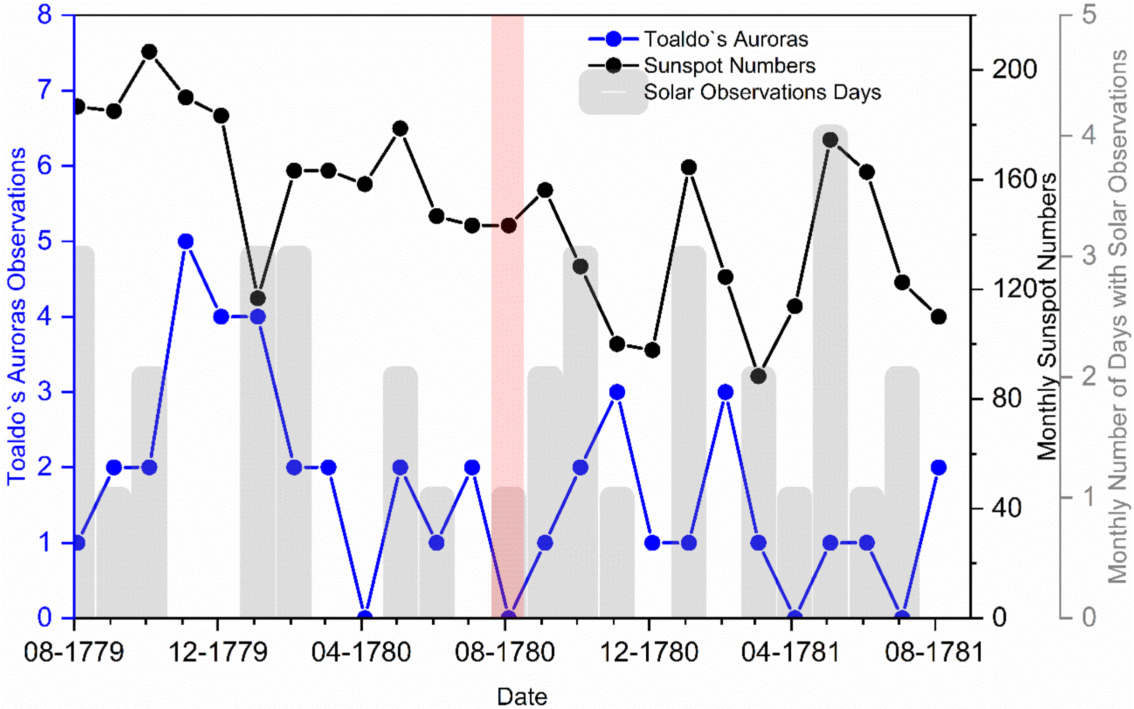


Figure 3: Annual sunspot numbers and number of days with solar observations (SILSO –WDC ; Clette et al.,2014; Clette and Lefevre 2016).



795 **Figure 4: Monthly sunspot numbers, days with solar observations and auroras from Toaldo catalogue from August 1779 to August 1781 (Dominguez-Castro et al., 2016; Vaquero et al. 2016).**