

Space Weather

Supporting Information for

**Temporal and Spatial Evolutions of a Large Sunspot Group and Great Auroral Storms
around the Carrington Event in 1859**

Hisashi Hayakawa (1-2)*, Yusuke Ebihara (3-4), David M. Willis (2, 5), Shin Toriumi (6),
Tomoya Iju (7), Kentaro Hattori (8), Matthew N. Wild (2), Denny M. Oliveira (9-10), Ilaria
Ermolli (11), José R. Ribeiro (12), Ana P. Correia (12), Ana I. Ribeiro (13-14), and Delores J.
Knipp (15-16)

- (1) Graduate School of Letters, Osaka University, 5600043, Toyonaka, Japan (JSPS Research Fellow).
- (2) UK Solar System Data Centre, Space Physics and Operations Division, RAL Space, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Harwell Oxford, Didcot, Oxfordshire, OX11 0QX, UK
- (3) Research Institute for Sustainable Humanosphere, Kyoto University, Uji, 6100011, Japan
- (4) Unit of Synergetic Studies for Space, Kyoto University, Kyoto, 6068306, Japan
- (5) Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, UK
- (6) Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan
- (7) National Astronomical Observatory of Japan, 1818588, Mitaka, Japan.
- (8) Graduate School of Science, Kyoto University, Kyoto, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto, 6068502, Japan
- (9) Goddard Planetary Heliophysics Institute, University of Maryland Baltimore County, 1000 Hilltop Circle Baltimore MD 21250, United States
- (10) NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt MD 21021, United States
- (11) INAF Osservatorio Astronomico di Roma, Via Frascati 33 00078 Monte Porzio Catone, Italy
- (12) Escola Secundária Henrique Medina, Esposende Av. Dr. Henrique Barros Lima 4740-203 Esposende, Portugal
- (13) EPIUnit - Instituto de Saúde Pública, Universidade do Porto Rua das Taipas, 135 4050-600 Porto, Portugal.
- (14) Departamento de Ciências da Saúde Pública e Forenses e Educação Médica, Faculdade de Medicina, Universidade do Porto, 4200-319 Porto, Portugal.

(15) High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, CO 80307, USA

(16) Smead Aerospace Engineering Sciences Department, University of Colorado Boulder, Boulder, CO, CO 80309, USA

Contents of this file

Supplementary Texts 1 – 2
Tables 1

Introduction

Appendices 1 – 2 show the source documents for the contemporary observational records of sunspots and aurorae, respectively. The auroral records are summarized in Table S1.

Supplementary Texts.

Supplementary Text 1: Source Documents for Contemporary Sunspot Observations

RAS MSS Carrington 1.3, Sunspot observations, the Royal Astronomical Society

RAS MSS Schwabe 31, the Royal Astronomical Society

OAR MS B13, Angelo Secchi, Macchie Solari 1859, Archivio INAF Osservatorio Astronomico di Roma

Supplementary Texts 2: Source Documents for Contemporary Auroral Reports

Here, we show source documents for auroral reports. In order to keep their traceability, we show their bibliography in their original language. Bibliographies of published sources in Japan are given in source name, editor or author, name of publication, year of publication, and page number(s). Those of unpublished materials are given with source name, name of data holder, shelf marks, and folio number(s). When we could not access the whole document, we provided their section name.

Supplementary Text 2.1. Russian Reports:

Kupffer, A. (1860) *Annales de l'observatoire physique central de Russie – Année 1859*, St. Petersbourg.

Supplementary Text 2.2. European Reports:

MS 117.2: Thirteen volumes of meteorological records for Armagh, 1833-1987, Armagh Observatory MS 117.2. 1859 August and September.

Pt1: A Nação, 1859-08-30

Pt2: O Commercio do Porto, 1859-08-30

Pt3: O Viannense, 1859-08-29

Pt4: O Bracarense, 1859-08-30

Pt5: O Angrense, 1859-09-08

Pt6: O Fayalense, 1859-09-04

Pt7: A Aurora do Lima, 1859-08-29

Pt8: O Direito, 1859-08-29
 Pt9: O Jornal do Porto, 1859-09-01
 Pt10: O Tribuno Popular, 1859-09-03
 Pt11: A Opinião, 1859-08-30
 Pt12: Diário do Governo, 1859-09-16
 Pt13: O Futuro, 1859-08-30
 Pt14: A Terceira, 1859-09-03
 Pt15: O Independente, 1859-09-01
 Es1: Diario de Barcelona de Avisos y Noticias, 1859-08-31
 Es2: Diario de Barcelona de Avisos y Noticias, 1859-09-01
 Es3: El Ateneo, 1859-09-06
 Es4: El Isleño, 1859-08-29
 Es5: Revista de las Ciencias, 1860, pp. 501-503
 Es6: El Faro de la Montaña, 1859-09-01

Supplementary Text 2.3. Oceanian Reports:

NZ1: The Wellington Independent, 1859-08-30
 NZ2: The Colonist, 1859-08-30
 NZ3: The Nelson Examiner, 1859-08-31
 NZ4: The Southern Cross, 1859-09-02
 NZ5: The Taranaki Herald, 1859-09-03
 NZ6: The Littelton Times, 1859-09-03
 NZ7: The Southern Cross, 1859-09-09
 NZ8: The New-Zelander, 1859-09-17
 NZ9: The New-Zelander, 1859-09-17
 NZ10: The Littelton Times, 1859-09-28
 NZ11: The Nelson Examiner, 1859-09-07
 WAU1: Perth Gazette and Independent Journal of Politics and News, 1859-09-09
 WAU2: Inquirer and Commercial News, 1859-09-07
 WAU3: Inquirer and Commercial News, 1859-10-19

Supplementary Text 2.4. Japanese Reports:

HJ6: 綱領, 川添昭二『黒田家譜』1984, p. 270.
 HJ7: 楊軒日記, 新潟県教育委員会『長善館学塾史料』1974, p. 72
 HJ8: 安政六年日鑑 抄, 山形市史編集委員会編, 山形市史資料第 57 号, 1979, p.107,
 HJ9: 外宮子良館日記, 神宮文庫 MS 1-4626, f. 18a
 HJ10: 山脇弁治日記 安政六年 後, 秋田県立文書館蔵 Microfilm A-181, A2149-32-6, pp. 36-37

Supplementary Text 2.5. Mexican Newspapers

MX6: Diario Oficial del Supremo Gobierno, 1859-09-03
 MX7: La Sociedad, 1859-09-26

Table S1: Auroral reports recovered in this article from the observational sites in the Russian Empire, Ireland, Portugal, Spain, New Zealand, Australia, and Japan (see Appendix 2). Their ID, observational sites, geographic coordinate (latitude and longitude), MLAT (magnetic latitude), and the local mean time (LMT) of start and end of visibility are shown here. The observational time is converted to the universal time (UT), on the basis of their longitude/15. The prefix HJ signifies auroral reports from Japan, reports with ArM and date signify those from meteorological

records (MS 117.2) in the Armagh Observatory (see Butler and Hoskin, 1987), reports with Pt signifies Portuguese newspapers, reports with Es signify Spanish newspapers, reports with NZ signifies newspapers from New Zealand, reports with MX signify records from Mexico (see Hayakawa et al., 2018f), reports with WAU signifies newspapers from Western Australia, and reports prefixed with R signify Russian auroral observations from Kupffer (1860) together with their page numbers. In order to describe the continuity of auroral visibility beyond midnight, we define the observational dates between 06:00 and 30:00 (06:00 on the following day).

ID	Date			Site	Lat.	Long.	MLAT	Start	End
R53	1859	8	28	St. -Petersbourg	N59°56'	E30°16'	56.9°		
R463	1859	8	28	Sitka	N57°3'	W135°20'	59.3°		
ArM185908	1859	8	28	Armagh	N54°21'	W6°39'	58.8°		
Pt1	1859	8	28	Lisbon	N38°43'	W9°08'	44.3°	23:00	25:00
Pt2	1859	8	28	Porto	N41°09'	W8°37'	46.5°		
Pt2	1859	8	28	Foz do Douro	N41°09'	W8°41'	46.5°	23:00	26:00
Pt3	1859	8	28	Viana do Castelo	N41°42'	W8°50'	47.1°	23:00	25:00
Pt4	1859	8	28	Braga	N41°33'	W8°26'	46.9°	24:00	24:30
Pt5	1859	8	28	Angra do Heroísmo	N38°39'	W27°13'	47.1°		
Pt6	1859	8	28	Horta	N38°32'	W28°38'	47.2°	22:00	24:00
Pt7	1859	8	28	Viana do Castelo	N41°42'	W8°50'	47.1°	23:00	25:30
Pt8	1859	8	28	Porto	N41°09'	W8°37'	46.5°	24:30	25:00
Pt9	1859	8	28	Lisbon	N38°43'	W9°08'	44.3°	24:00	25:00
Pt10	1859	8	28	Viseu	N40°39'	W7°55'	45.9°	23:00	26:00
Pt11	1859	8	28	Lisbon	N38°43'	W9°08'	44.3°	23:00	27:00
Pt12	1859	8	28	Lisbon	N38°43'	W9°08'	44.3°	23:30	26:30
Pt13	1859	8	28	Lisbon	N38°43'	W9°08'	44.3°	24:00	25:00
Pt14	1859	8	28	Viana do Castelo	N41°42'	W8°50'	47.1°	23:00	
Pt15	1859	8	28	Braga	N41°33'	W8°26'	46.9°	24:00	26:00
Es1	1859	8	28	Barcelona	N41°23'	E02°10'	44.7°		
Es1	1859	8	28	Tarragona	N41°07'	E01°15'	44.6°		
Es2	1859	8	28	Mataró	N41°32'	E02°27'	44.8°	24:30	
Es3	1859	8	29	Ourense	N42°20'	W07°52'	47.5°	24:00	25:00
Es4	1859	8	28	Palma de Mallorca	N39°34'	E02°39'	42.9°		
Es5	1859	8	28	Pontevedra	N42°26'	W08°39'	47.8°		
Es5	1859	8	29	Pontevedra	N42°26'	W08°39'	47.8°		
Es6	1859	8	28	Figueres	N42°16'	E02°58'	45.4°	25:00	

ArM185908	1859	8	29	Armagh	N54°21'	W6°39'	58.8°		
NZ1	1859	8	29	Wellington	S41°18'	E174°47'	-46.0°		21:00
NZ2	1859	8	29	Nelson	S41°16'	E173°17'	-46.3°	18:30	21:00
NZ3	1859	8	29	Nelson	S41°16'	E173°17'	-46.3°		
NZ4	1859	8	29	Auckland	S36°51'	E174°46'	-41.7°		
NZ5	1859	8	29	New Plymouth	S39°04'	E174°04'	-44.0°	18:30	21:00
NZ8	1859	8	29	Auckland	S36°51'	E174°46'	-41.7°		
NZ9	1859	8	29	Turanga	S38°36'	E176°10'	-43.2°	19:30	22:00
NZ10	1859	8	29	Littelton	S43°36'	E172°43'	-48.7°		
Pt6	1859	9	1	Horta	N38°32'	W28°38'	47.2°	28:00	dawn
MX6	1859	9	1	Mexico City	N19°26'	W99°08'	31.5°	24:00	25:00
MX7	1859	9	1	Huichihuayan	N21°29'	W98°58'	30.8°		
HJ6	1859	9	2	Hakata	N33°35'	E130°23'	22.6°		
HJ7	1859	9	2	Niigata	N37°39'	E138°52'	27.2°	22:00	
HJ8	1859	9	2	Yamagata	N38°15'	E140°20'	27.9°		
HJ9	1859	9	2	Ise	N34°29'	E136°42'	23.9°	18:00	26:00
HJ10	1859	9	2	Koriyama	N39°13'	E140°25'	28.9°		
NZ6	1859	9	2	Littelton	S43°36'	E172°43'	-48.7°		
NZ7	1859	9	2	Auckland	S36°51'	E174°46'	-41.7°		
NZ10	1859	9	2	Littelton	S43°36'	E172°43'	-48.7°		
NZ11	1859	9	2	Nelson	S41°16'	E173°17'	-46.3°		
WAU1	1859	9	2	Perth	S31°57'	E115°51'	-43.3°	19:00	28:00
WAU2	1859	9	2	Perth	S31°57'	E115°51'	-43.3°	20:00	26:00
WAU3	1859	9	2	York	S31°53'	E116°46'	-43.3°	19:00	
R57	1859	9	2	St. -Petersbourg	N59°56'	E30°16'	56.9°	22:00	
R143	1859	9	2	Catherinbourg	N56°49'	E60°35'	49.1°	21:30	25:00
R229	1859	9	3	Barnaoul	N53°20'	E83°47'	43.2°		
R315	1859	9	2	Nertchinsk	N51°19'	E119°44'	40.0°	20:00	24:00
R467	1859	9	1	Sitka	N57°3'	W135°20'	59.3°	21:00	22:00
R545	1859	9	3	Zlatoouste	N55°12'	E59°43'	47.7°	20:00	22:00
R545	1859	9	4	Zlatoouste	N55°12'	E59°43'	47.7°	21:30	22:30
R577	1859	9	2	Lougan	N48°35'	E39°20'	44.5°	21:00	
R577	1859	9	3	Lougan	N48°35'	E39°20'	44.5°	21:30	
Rs245	1859	9	3	Tobolsk	N58°12'	E68°15'	49.5°	22:00	
ArM185909	1859	9	2	Armagh	N54°21'	W6°39'	58.8°		

ArM185909	1859	9	3	Armagh	N54°21'	W6°39'	58.8°		
ArM185909	1859	9	4	Armagh	N54°21'	W6°39'	58.8°		