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The Carrington Solar Flares of 1859: Consequences on Life

C. Muller

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Abstract The beginning of September 1859 was the occasion of the first and unique observation of a giant solar white light flare, auroral displays were observed at low latitudes and geomagnetic observatories recorded exceptional storms. This paper reviews the impact of the event on the earth system with a special emphasis on living processes using the historical record and current scientific analysis. The data used includes reports from the telegraph operators, mortality and morbidity records, proxies as agricultural production. Comparisons with later solar flare events will be attempted on the basis of the record and the consequences of an event of comparable magnitude to the 1859 set of flares will be discussed.

Keywords Aurorae · History · Perturbations

Introduction

Antiquity and Early Electrical Telegraphic and Geophysics Observations

Auroral observations have been reported since the highest antiquity and are indicated in the Bible and by Aristotle. The earlier written cultures are unfortunately limited to the northern mid-latitudes, all these ancient aurorae have a common point, they appear in red to the North. There are no reliable records of a luminous phenomenon covering the entire sky and showing a full spectrum of colours. For example, in the Bible: “And now men see not the light which is bright in the skies; but the wind passeth, and cleanseth them. Out of the north cometh golden splendour, about God is terrible majesty” Jewish Publication Society Bible, Job 37: 21–22. Aristotle made the link with meteorology as he associates the red colour with the influence of a long path in air as sunrise and dawns exhibit also the same red colours. However, no systematic records of aurorae exist before the eighteenth century. As early scientists were very much concerned about periodic phenomena, this is an indication that no evident return

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C. Muller (✉)
Belgian Users Support Operation Centre, Avenue Circulaire, 3, 1180 Brussels, Belgium
e-mail: Christian.muller@busoc.be

frequency was observed. Magnetism and electricity entered science only in the eighteenth century while sunspot observation had begun with Galileo in the early seventeenth century. The situation changed with Gauss (Stern, 1989) who for the first time associated magnetic and auroral observations, discovering magnetic storms and their coincidence with aurora. Moreover, Gauss and Weber developed an electrical two wires telegraph in 1833 for the synchronisation of observations and tested the transmission of words through an elaborate code (Stevens et al. 1838). Their scientific breakthrough led to the first commercial patent by Wheatstone in 1837 for a five wires telegraph leading immediately to the exploitation of lines between London, Liverpool, Manchester and Birmingham along the new railroad network. This telegraph was using a code able to transmit 20 letters, the other ones having to be omitted. The continental testing of this system in 1840 involved the Director of the Royal Observatory of Belgium, Quetelet and Gauss. The scientific objective being network science coordinating magnetic observatories (Quetelet, 1840). Similar developments in the United States led Morse to design a stable telegraph with a coding system able to transmit many more characters which the US Supreme Court recognized in 1854 as the only patented telegraph system. However, the Wheatstone network was the first to report electrical perturbations related to an auroral phenomenon in 1847 (Barlow, 1849), Barlow was the chief engineer of the East Midlands Railway and also a dedicated observer, his relations with established scientists certainly helped the publication of this observation twenty years before the Maxwell equations. Barlow had observed spontaneous currents on four lines of his idle network and these induced currents subsisted when he put the batteries on to check the simultaneity of the observations using the network itself. This type of perturbation was fundamentally different from the electrical perturbations usually observed in thunderstorms and which were very local.

In 1859, the telegraphic network had expanded to the entire North-Western Europe, the Eastern United States and a few lines were operational in India and Australia while the Japanese network was still at the experimental stage. The first South American line was laid in 1866, thus only Europe and the Eastern United States had really operational networks in 1859 (Figs. 1 and 2).

Unfortunately, in 1859, the telegraph operators had only an elementary knowledge of electricity; they knew about basic laws like the Ohm law but could not understand the phenomena of induction or the oscillation effects appearing on long lines. The Maxwell equations were published only in 1865 (Maxwell, 1865) and gave a first coherent frame to the empirical laws derived by earlier physicists, their application to telegraph design were immediate but it took Oliver Heaviside, himself a former telegraph operator to write them in a form usable by all engineers and physicists and to multiply their applications in a set of papers from 1872 to 1894 (Heaviside, 1894). The increase of the telegraph stability resulting from a better management of grounding and induction loops mitigated the effect of magnetic storms in such a way that they became again a concern only when radio-propagation developed in its turn.

The Solar and Magnetic Events of 1859

A conjunction of events led to the observation of the white flare which was to be known as the Carrington event, the solar cycle had just been identified by Schwabe before the telegraphic perturbations of 1844 and Sabine had observed the link between sunspots and magnetic storms during this same perturbation observed from Toronto and Hobart (Tasmania) stations (Sabine, 1854). Sabine was a British military officer who was on leave from active service during most of his career in order to set a network of magnetic observatories in the hope that magnetic observations would once provide a reliable system of geolocalisation, his network extended to the entire British empire and he managed international coordination with scientists in continental Europe including Gauss and Quètelet. Sabine supported also the solar observations of

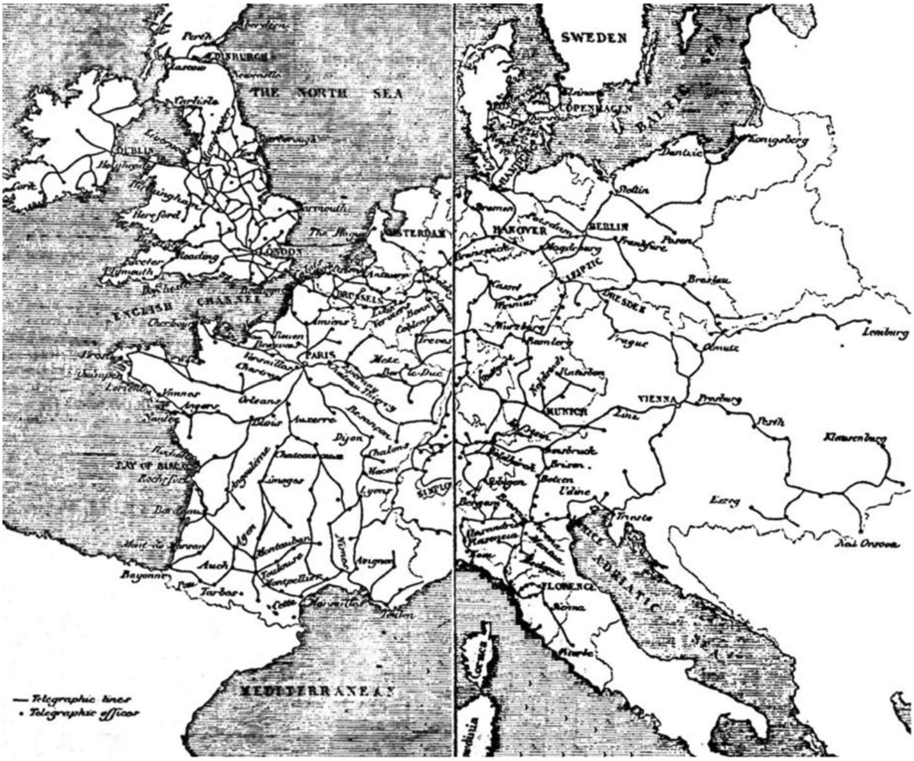

Fig. 1 European telegraph networks in 1854, Spain, Italy and the Ottoman empire lack coverage, the lines are of unequal lengths, the longer lines reaching the borders of the Austro-Hungarian empire . The European geomorphology leads to a variety of ground electrical conductivity properties while the network hardware and operator procedures show national variations. Shorter lines lead to a better grounding and have mitigated the worst consequences of ground induced currents (Stevens et al. 2012)

Carrington in whom he appreciated an objective and unprejudiced observer. Carrington had not been selected for some of the most prominent astronomy positions in England due to the preference given to mathematicians, also, the Royal Astronomer, Airy was extremely suspicious of any relations between astronomical phenomena and electricity. Most of the funding of Carrington's observatory was thus coming from the benefits of his family brewery and his solar publications would probably never have been recognized if they had not received the constant support of Sabine. The biography of Carrington and its tragic aspects have been detailed by Clark (2007), however his works are far from forgotten, his name was given to both the solar rotation and the numbering system of solar cycle. The only public recognition he got in his lifetime from the international astronomical community was for his atlas of circumpolar stars (Carrington, 1855). From a solar point of view, he managed complex observations of the 1852 solar eclipse in Scandinavia using a combination of naïve and educated observers to be sure that the described coronal aspects were observer independent and proved effectively that the coronal structures were of solar origin and not originating from the moon (Carrington, 1852). He went on by beginning a series of sunspot observations in a systematic way with the hope that this new record could be put in relation with other geophysics measurements as magnetic or meteorological observations. Unfortunately, he had to interrupt his series after 1861 in relation to the

Fig. 2 the 1854 US network, the lines are longer and a rockier surface increases the effectiveness of ground induced currents, longer lines demand a higher battery power leading more easily to accidents. A standard procedure was to fight perturbations by doubling the batteries. The combination of these parameters with operator's impatience might be the cause of dangerous sparks at several stations. (Stevens et al. 2012)

management of his brewery and private life problems worth of a Dostoyevsky novel until his untimely death at the age of 49 in 1875 (Clark, 2007).

In this context, Carrington, Sabine and others were well positioned to observe the solar maximum of 1859, between the end of August and the 6th of September, auroral displays, sunspots and magnetic storms occurred every day, the most spectacular artefact being the Carrington white flare observed on September 1, 1859 (Carrington, 1859) (Figs. 3 and 4).

The main result of these observations is that the storm shows a delay of about 18 h versus the flare which is interpreted now in term of propagation of the solar wind (Tsurutani et al. 2003), these magnetic perturbations will be the cause of both the ground induced currents which disturbed the telegraph network and of the auroral displays.

Effects on the Telegraph Network

The reports of the operators are narrative as they did not have standardized monitoring equipment and no record of a tension or current was published at the time. Their only instrument was a needle display showing the activity on the wire and a clock announcing the beginning of a new message, after receiving a complete message, the operators would send

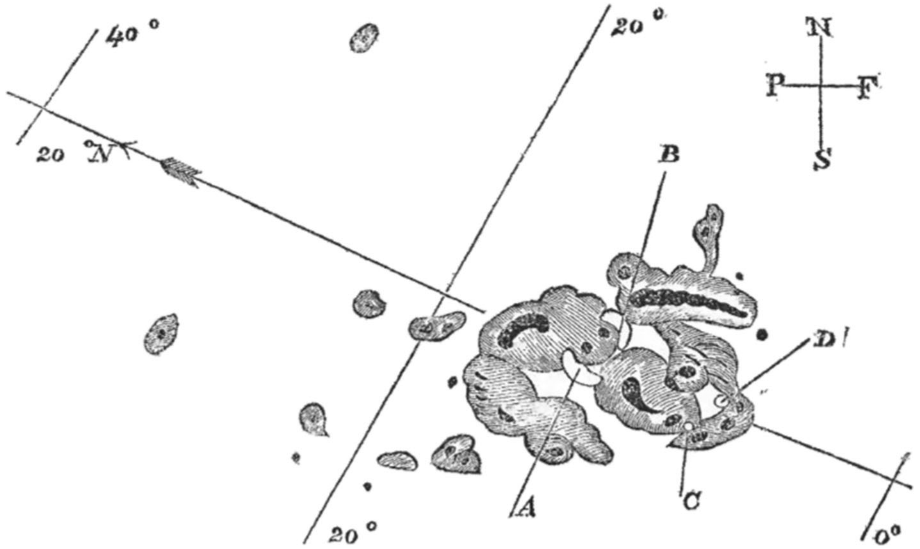

Fig. 3 Carrington drawing of the sets of sunspots of September 1, 1859, the zones marked A and B was the location of a white flash lasting at least five minutes. (Carrington, 1859). As usual for him, Carrington was careful to remove the observer's equation and had coordinated his observations with an amateur independent observer (Hodgson, 1860). Thus white flare was the first to be reported. Nowadays rapid CCD's detectors allow the monitoring of much smaller flares. A flare of the amplitude observed by Carrington and Hodgson has however never been seen again. Simultaneously, the Sabine magnetic network observed the onset of magnetic storms, these data were recently reviewed and analysed by Cliver and Svalgaard (2004) and Tsurutani et al. (2003) (Fig. 5)

again a clock signal to the emitting station to acknowledge good reception. The telegraphic equipment was very far from standard as all European countries had developed national solutions. Even in the United States, several independent companies had built networks of their own designs before the U.S. Supreme Court decided in favour of the Morse patent in 1854. Especially, the grounding of equipment was empirical and more concerned about lightning protection than avoiding induced currents. Also, as a general rule, the conductivity of soils had not been investigated. In this respect two European cases are given as examples: the Brussels station and the Noyelle station. Brussels was already in 1859 a communication node linked to London, Paris, Berlin and other European cities, it was thus receiving signals from various networks in different locations, an extensive description of the perturbations was given by the Director of the Brussels Observatory, himself a pioneer of magnetic observations (Quetelet, 1859). On the contrary Noyelle situated on the river Somme bay in France was an intermediate telegraphic station of the 'Réseau des Chemins de Fer du Nord' between the even smaller stations of Rue and Abbeville, the responsible of the station was by chance also an amateur astronomer (Lartigue, 1859) and he gave an elaborate description of the aurora observed in the night from the 28 to the 29 of August, he indicates explicitly that he did not observe any perturbations on his telegraphic lines and that the three messages he had to process during the night were unperturbed by the auroral display and the related magnetic storm.

Quetelet in Brussels indicates that on August 29, from around 0 h to about 1 h30, no communications with the other European capitals was possible, the perturbation having begun by the random noise of the clocks which normally indicated the impulsion announcing a new message, he indicates also that the operators also observed the aurora in Paris, Brussels and

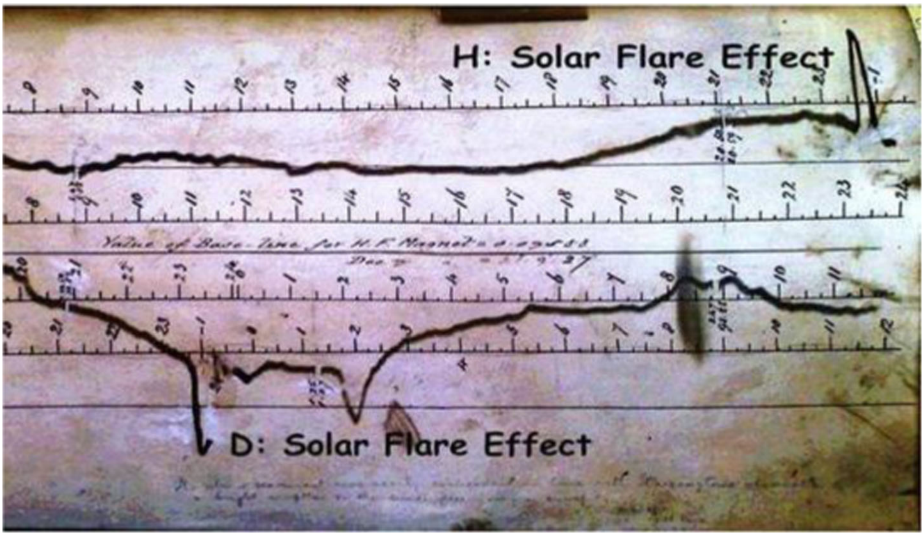

Fig. 4 Trace of the horizontal component of Earth's magnetic field from Kew Observatory for 1–2 September 1859, showing the magnetic crochet at 11:15 UT on 1 September and the great geomagnetic storm that followed 17.6 h later and drove the record off scale. (Cliver et al., 2004)

The Hague, the operators of the Berlin station reported not having been out or their station but the bad weather noted by observers in North-Western Germany (Münster) might also have been present in Berlin. The segment of the London-Brussels lines between Ostend and

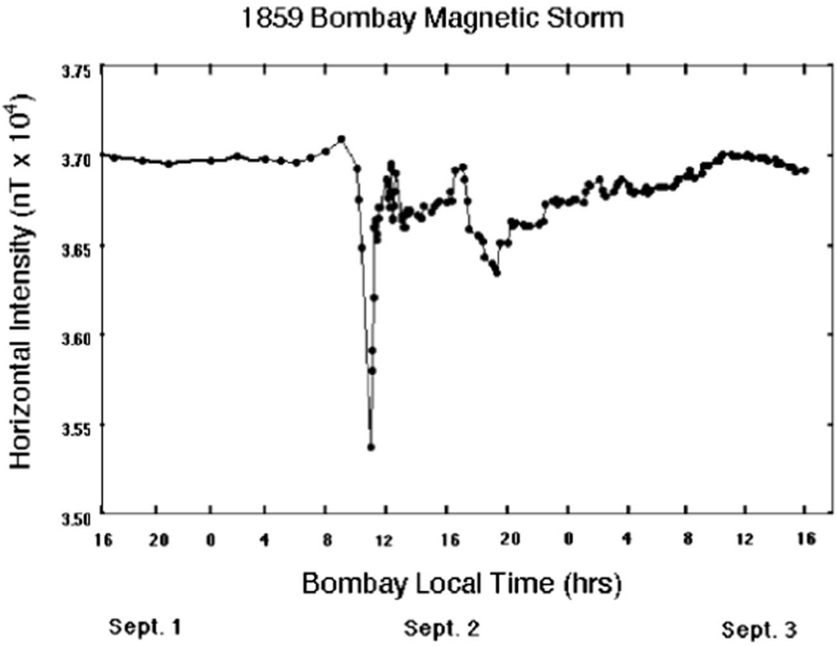

Fig. 5 The Colaba (Bombay) magnetogram for the 1–2 September 1859 magnetic storm. (Tsurutani et al. 2003)

Dover staid however unusable between around midnight and three in the morning, this line as it was crossing the channel had the best insolation. At three the operators decided to increase the batteries power so that they could regain control of the line against the induced currents. This procedure had been advised by Jacobi (1844) in the first operations of the Russian telegraph in order to force the signal and avoid interruption of communications. It should be noted that Jacobi, himself the brother of the well-known mathematician, attributes the invention of the telegraph to Gauss or Schilling or even earlier. In Ostend, this procedure did not produce any damage, however, it is frequently reported that American stations took fire when the combination of induced and direct currents led to sparks which lit improperly stowed paper and chemicals, at least one operator was stunned by sparks (Anonymous, 1859). Other operators were much more subtle, the Portland to Boston line operated on the ground induced current and the New York Times gives a vivid account on the exchange between the operators (Anonymous, 1859). The induced current was also exploited with success by the founder of the Australian telegraph (McGowan, 1860). McGowan was operating from Melbourne and could transmit without batteries on a 50 km. line. He indicates also the relation with the aurora australis and adds that he had applied a similar procedure during an aurora in Upper-Canada in 1847.

The effects of the ground induced currents were thus worldwide. Unfortunately, no African or South American telegraph lines were active at the time and the only operational Asian telegraph line in India did not report any specific trouble, probably also relating to the sedimentary character of the soil near Mumbai.

Economic Effects of the Telegraphic Perturbations

Telegraphic lines were the only electronic communication media of the time and their main users were governments for the fast dispatch of orders, stock exchange agents and the press. The only record which could be investigated is that of the press, the media analysed are two newspapers: the “Journal des Débats“ from Paris and the “London Times”. the “Journal des Débats” was not only read by the French intellectual bourgeoisie, it was also the reference for all European diplomacy due to its reports and political analysis. Most of the reports were based on telegraphic messages of the correspondents, the newspaper contained also a weather report from most French and European stations. None of these elements appear to have been perturbed in the issues from August 28 to September 6. The newspaper indicates reports of the aurora without mention of electric or magnetic effects. The same applies to the “London Times” where the aurora was described by the weather correspondent without any mention of telegraphic perturbations, there also, information on stock exchange and ship moves seems not to have suffered from any communication difficulties.

As shown in the Brussels case, the network was operational again after a few hours of perturbation, the backlog of messages was transmitted and the incident did not have any effect on the further development of new long lines. The U.S. transcontinental line was established in 1861 and the reliability of the electric telegraph was so well trusted that the Pony Express messaging service stopped its transcontinental operation almost immediately (IEEE 2013).

In conclusion, the economy was not affected at all by the communication disruptions related by the magnetic storms of 1859.

Effects on Ozone and Atmospheric Chemistry

In 1859, ozone was measured through a chemical technique involving the exposition of papers imbibed with potassium iodide. The number of stations was high as the measured “ozone” was supposed to correlate with epidemics; it was already identified as an active form of oxygen. Only one observer in Versailles (Bérigny, 1859) increased the frequency of operations during the Carrington event period. He found an enhancement during the night, despite the fact that the night was dry (both from the Versailles weather report and from the fact that he could observe the aurora). As usual, the measurement procedures were not standard and different in Prussia, France and Belgium. When ozone was recognized as the O_3 molecule, it was found that the paper technique measured a sum of oxidants including hydrogen peroxide and formaldehyde and the whole data set was dismissed as yielding values which were exaggerated. However, Van Batselaer (1893) performed a set of comparisons with the more modern technique used in the Parc Montsouris station in Paris and found at least a qualitative agreement. I would thus follow a dedicated observer as Bérigny by stating that the tropospheric ozone increased by around 20 % in the night from the 28th to the 29th of August 1859. This would come from an increase in chemical activity related to an increased UV penetration in the previous day due to the direct solar flare and the temporary destruction of stratospheric ozone.

The increase observed is thus significant but much less important than the increases observed (around 100 %) presently in relation to the anthropogenic precursor gases release, thus air quality was not significantly affected by the magnetic storms at middle latitudes.

More recently, ice core studies have revealed a coincidence of high nitrate in the Greenland GISP ice core for the same year (Shea and Smart, 2004, Shea et al., 2006)) but unfortunately, this coincidence does not reproduce in other ice cores and those have shown other nitrate maxima which could be correlated to biomass burning. (Wolff et al. 2012). However, this result would be important if it proved that magnetic storms can lead to small footprints chemical perturbations in the lower troposphere at high latitudes. This only coincidence cannot thus even be used to estimate the frequency of Carrington like events.

Effects on Agriculture

In 1801, William Herschell established a correlation between wheat prices as reported by Adam Smith and solar activity (Herschel 1801). The price of wheat was indeed decreasing again in the 1850–1865 period despite the fact that farm workers were massively immigrating to the industrial cities, but this was related to legislation favouring imports precisely to provide cheap food to the new industrial workers and was not related to more favourable meteorological conditions. Carrington (1863), also a brewer and thus knowledgeable of the cereal market, arrives at the same conclusions in an annex at the end of his solar activity atlas.

Ranking of French wines began in 1855 as production was exploding due also to the demand of industrial workers and of the enriched bourgeoisie. Wine quality has often been related to solar activity as the two excellent years of 1947 and 1959 coincide with the two solar maxima encircling the International Geophysical Year. The result was also disappointing there, in 1859, the good wines had a good year while the ordinary wines were worse than expected due to a vine disease: oidum, a parasite which should normally have been inhibited by oxidants and a higher UV.

It can be concluded again that no detectable effect of the event on agriculture can be assessed from the record.

Effects on Health

Bérigny (1859) as most of the ozone observers of the time was an epidemiologist and wanted to find precursors or inhibitors of diseases in ozone and other parameters like solar activity or in his specific case, relations between electricity and ozone. This was connected with the pre-Pasteur theory of miasmas, a subtle set of fluids which would favour spontaneous generation of pathogens in the air, miasmas should have been sensitive to ozone and high ozone would have protected against diseases. Pasteur solved later a large number of epidemic problems by identifying the vector and the agent of the disease and by specifically destroying them without considering any reference to miasmas; these repeated successes killed the theory of spontaneous generation and the hypothesis of miasmas, leading unfortunately to a discontinuation of ozone large scale monitoring.

The mortality and morbidity record was searched for any suspect event related with the perturbations, the well maintained Boston statistic for 1859–1860 shows nothing abnormal: higher mortality in February and lower mortality in September do not show any differences with the previous years. Better statistics are available for the 20th century and a much more complete morbidity study gives the same results (Feinleib et al., 1975), no relations appear between solar activity and the human mortality, even for the cardio-vascular diseases. On the contrary, a detailed study of galactic cosmic rays at the same period shows a correlation with human cancer. (Juckett, 2007). The 20th and 21st centuries show also a progress in the electronic monitoring of public health and cardio-vascular emergencies. A large body of Russian literature, especially at high latitudes show correlations between magnetic activity and human heart rate variations. Studies on the relation between these observations and public health continue (Belisheva et al., 2011, Chernouss et al., 2001).

The transcripts of the conversations of American telegraph operators quoted above (Anonymous, 1859) show that their cognitive performances were not affected; the US press of the time indicates some anecdotic instances of abnormal behaviour like an increase of public drunkenness in the Garden section of New-Orleans. The only statistical anomaly which could be found is an increase in birth rate in the Seine department (Paris and surroundings) in April and May 1860 (Voranger, 1953). Voranger (1953) attributes this effect to the 1859 summer temperature; the data however are quite ambiguous as other fluctuation causes are possible. The Versailles temperature record corresponding to the Bérigny (1859) observations is in the seasonal norms and does not show hot weather for the magnetic storm days. The only conclusion that could then be drawn from this isolated case is that the magnetic storm did not have a negative influence on fertility.

Conclusions Relating to the 1859 Carrington Event

The 1859 solar flares and magnetic storms did not generate measurable effects nor on economy nor on public health. The effect on the electric telegraph were mitigated by the operator empirical skills which they had developed during previous magnetic storms, thunderstorms or equipment malfunctions.

Lessons for the 21st Century

The space age has led to important discoveries on solar activity, during a solar storm, we know that the sun sends us various high energy radiations and charged particles which were unknown in 1859, X rays, CME's, extreme UV, Lyman alpha and even UV below 240 nm were unknown before high altitude balloons and rockets brought instruments above the ozone layer. Other events which could be relevant as inversions of the magnetic fields should also enter into consideration as they are studied now. (Glassmeier and Vogt 2010).

Radio-communications were of course also absent in 1859, a global blackout of any communications involving ionospheric effects would be the normal consequence as well as disruption of electronic equipment including positioning systems. These effects should be considered as any natural disaster by redundancy and planning for mitigation and recovery. Already in 1916 when a solar storm cut transatlantic wireless transmissions, the British cable system could replace them transparently to the user. Presently, communication protocols are constantly improved to take into account network failures and are tested on the International Space Station.

An important perturbation happened in space in early November 2003 and is known as the Halloween event. It is estimated that it was significantly weaker than the Carrington event (Viljanen et al. 2014). The operators of the different satellites put them in standby mode during the event. The event and consequences are described by Schieb and Gibson (2011), only one satellite, the Japanese ADEOS-2 was partly damaged and most of the satellites active at the time exceeded their nominal lifetime. However, degradation of redundant circuits in the satellites cannot be excluded as an element of their failure, sometime several years after their contractual lifetime. No public report exists on the consequences on the ISS astronauts, B.USOC was operating at the time and it was noticed that they were asked to check their dosimeters and NASA commanded astronauts aboard the ISS to seek precautionary shelter to avoid excessive levels of radiation . After the flight, they all pursued their careers without mention of health problems.

Extrapolation to current equipment is not easy but major communication equipment built around optical fibres links are much less sensitive to perturbations than the 1859 network, the biggest issue with ground induced currents would reside now in the power distribution network with long lines, high voltages and sensitive transformers. Regional electric black-outs have already happened and corrective procedures have been taken, in particular, the phase synchronisation of the power network has been increased and the large power distribution companies while never guaranteeing continuous supply study tend to care for business continuity for which now an ISO norm has been designed: “ISO 22301 - Societal security – Business continuity management systems Requirements”. (http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=50038). The set of procedures developed prepares for rapid recovery mitigation of natural disasters.

In general conclusion, previous black-outs have alerted the different stakeholders of the power and communication networks and readiness level keeps increasing at both national and international levels.

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