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Key Points:
- The magnetic storm of November 1882 caused widespread disruption to telegraph and telephone systems
- The storm had a maximum $-Dst$ of approximately 386 nT; the 4 day average *aa* was the highest since 1868
- The effects of the storm inform understanding of solar-terrestrial interaction and geoelectric hazards

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The Electric Storm of November 1882

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Abstract In November 1882, an intense magnetic storm related to a large sunspot group caused widespread interference to telegraph and telephone systems and provided spectacular and unusual auroral displays. The (ring current) storm time disturbance index for this storm reached maximum $-Dst \approx 386$ nT, comparable to Halloween storm of 29–31 October 2003, but from 17 to 20 November the *aa* midlatitude geomagnetic disturbance index averaged 214.25 nT, the highest 4 day level of disturbance since the beginning of *aa* index in 1868. This storm contributed to scientists' understanding of the reality of solar-terrestrial interaction. Past occurrences of magnetic storms, like that of November 1882, can inform modern evaluations of the deleterious effects that a magnetic superstorm might have on technological systems of importance to society.

1. Introduction

The front page of the New York Times (dated 18 November 1882) declared that the "storm of electricity" of the day before had seriously affected the "workings of the telegraph lines both on the land and in the sea." The storm brought telegraph business east of the Mississippi and north of Washington to a "standstill," and it "prevented service over the Mexican and Cuban cables as well as the Atlantic cables." People attempting to use Metropolitan Telephone Company lines "heard buzzing, ringing noise."

According to the Chicago Daily Tribune (dated 18 November 1882), the "electrical storm" was "a magnetic demonstration of remarkable force and duration," one that "old telegraphers" said was "unparalleled in intensity." The affected territory extended from "New York to Omaha and from Kansas City north to the end of the wires." The switchboard in the Western Union office was said to have "ignited half a dozen times," "melted" several instruments, and to have left "only one wire out of fifteen between Chicago and New York [in] operation."

Telegraph messages could not be transmitted on transatlantic cables due to "Earth currents" of "extraordinary strength" (Graves, 1883). In France, telephones rang spontaneously, and many telephone conversations were impossible (de Lalagade, 1882). In Scotland, signal bells in railway cabins rang, as if by the train's conductor, and telegraph operations were temporarily stopped in some parts of the country (Maunder, 1892, p. 91).

The "electric storm" of November 1882 was also described in the newspapers as an "auroral storm" (e.g., The Baltimore Sun, 18 November 1882). In many night skies around the world, beautiful aurorae were seen (e.g., Von Tunzelmann, 1884). In Europe, aurorae were seen as far south as Rome (Ommanney, 1882). In the United States, they were seen in San Diego, California; Yuma, Arizona; Galveston Texas; and Punta Rassa, Florida (Monthly Weather Review, 1882). The Los Angeles Times (18 November 1882) reported that the "heavens presented a grand spectacle." The Sonoma Democrat (25 November 1882), a newspaper from a small town in northern California, described the aurora as a "strange phenomenon which was at once the wonder and admiration of the ancients, and is scarcely less a mystery in our day."

An electrician of the Western Union Telegraph Company, Chicago, said "There is nobody, I presume, who knows the real cause" of the electrical storm. But "it is very generally believed that the aurora borealis" seen during the preceding nights "had something to do with it" (Chicago Daily Tribune, dated 18 November 1882). Other reports described the simultaneous sighting of aurora borealis and telegraph interference as evidence of an "overcharging of the atmosphere with electric fluid" (New York Times, dated 18 November 1882).

2. Electric Revolution

In the late nineteenth century, much of the world was in the midst of an electrical revolution. The telegraph had emerged as an important communications technology. Transatlantic telegraph lines began operation in

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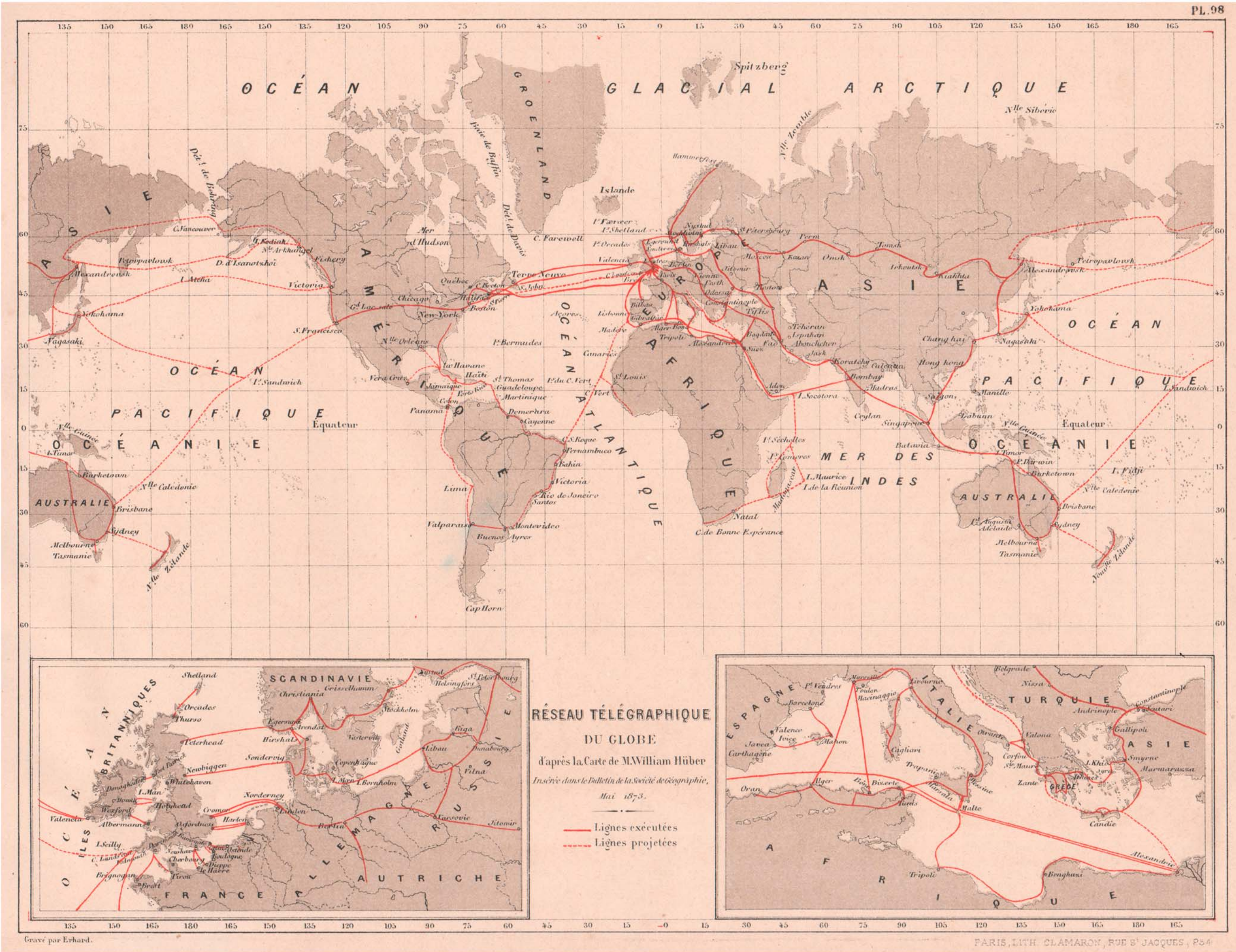

Figure 1. Map showing global telegraph lines in 1873.

1858, and just a decade and a half later, cables connected major cities around the world; a map of the primary cables is given in Figure 1. In the United States, Alexander Graham Bell was granted an American patent for the telephone in 1876. Thomas Alva Edison invented the light bulb in 1879, and in 1882, in direct competition with gas lighting utility companies, his Edison Illuminating Company was supplying electricity to power light bulbs for a small part of lower Manhattan in New York City. It was an era in which innovation was celebrated, and Edison was one of the era's most famous celebrities (e.g., Stross, 2007).

When a newspaper reporter asked "Mr. Edison" for an explanation of the extraordinary events of 17 November, he responded in the practical terms one would expect from an engineer of those days: "There was a difference of electric pressure in different parts of the Earth. If the Earth at New York was at zero and the Earth at Boston was electrified there would be a current flow through the Earth to New York to equalize the Earth. Electricity, like water, must find its level." With the grounding of a telegraph wire to the Earth, "a superabundant amount of electricity passes through the wire" (Washington Post, 20 November 1882).

One of Edison's managers in Milwaukee, Wisconsin, "put one of his electric lamps on a telegraph wire during the storm," and it was estimated that "when it was lighted up to about thirty candles, the pressure on the wire [would have been] equal to eight horse power." Edison speculated that the "amount of current which must circulate between areas of high and low electric pressure in the Earth must be equal to millions of horsepower. The Earth was, so to put it, a dead level, the aurora came and electrified it." (Washington Post, 20 November 1882).

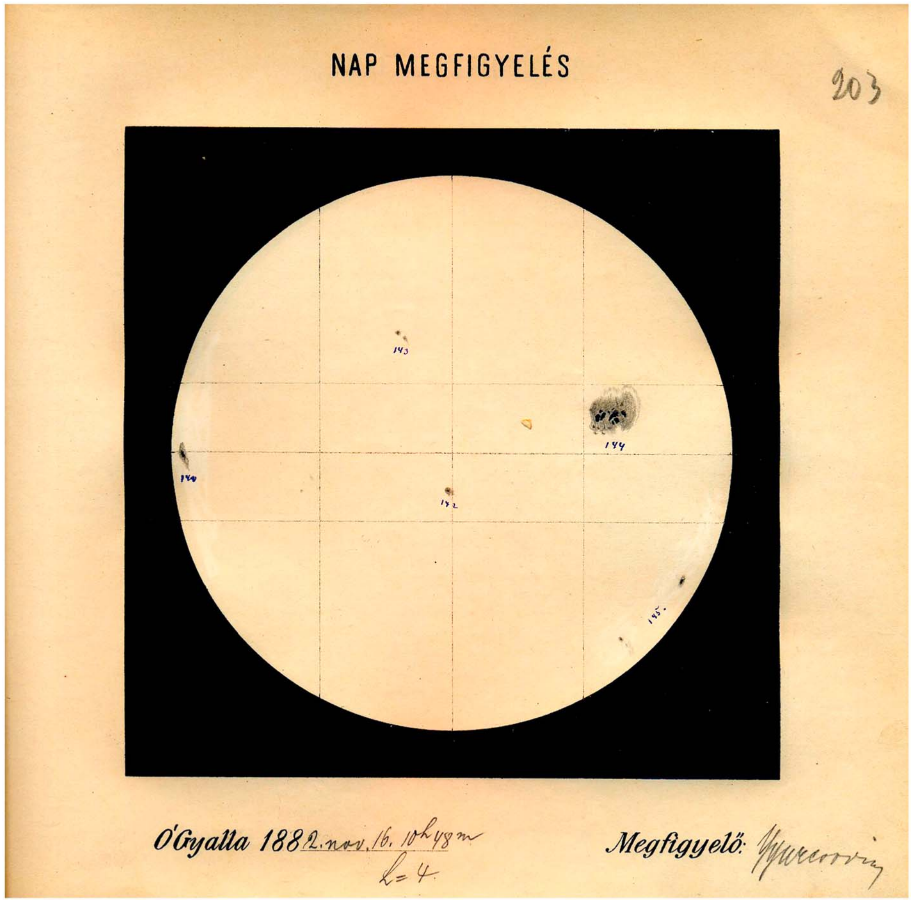

Figure 2. Drawing of the Sun for 16 November 1882 from the Ógyalla Observatory in Hungary (Baranyi et al., 2016).

3. Sunspot

On 20 October 1882, astronomers, monitoring the Sun through telescopes, noted the formation a new sunspot. But by 28 October, with solar rotation, the spot had passed out of sight over the Sun's western limb and then came over the eastern limb on 12 November. In the intervening time, it grew to become what the American astronomer, John Brashear of Pennsylvania, described as "an object of singular beauty" (Washington Post, 21 November 1882). This can be appreciated from a drawing that astronomers at the Ógyalla Observatory in Hungary made of the Sun on 16 November 1882 and which is shown in Figure 2. By 18 November, its area reached a maximum size of 2,417 millionths of the solar disk (e.g., Richardson, 1937), big enough to be easily seen by the naked eye.

In 1873, the Astronomer Royal, George Biddell Airy, hired Edward Walter Maunder (e.g., Crommelin, 1928) to work at the Royal Observatory in Greenwich, England, as a spectroscopic astronomer and observer of sunspots; Maunder and his wife Annie would go on to become prolific authors of scientific and popular works (e.g., Dalla & Fletcher, 2016; Kinder, 2008). Long after the events of November 1882, he would recall seeing the sunspot on the 18th: "… Queen Victoria was holding a review in Hyde Park. The morning was somewhat foggy, and the Sun shone dull and red through the thick air, so that it was easy to look at him. On this occasion there was a great spot on the Sun; so big that it caught the attention of the soldiers who were marching across Blackheath, to the review, and they pointed it out to each other" (Maunder & Maunder, 1908, p. 105).

Recognizing the unusual dimension of the sunspot, Maunder went quickly to the Observatory's telescopes, where he observed "brilliant reversals of the H-alpha and H-beta spectral lines" (bright instead of dark) over the spot, indicative of flaring. (Royal Observatory, Greenwich, 1955, p. 62, Ref. 38) "… shooting up from almost every part of [the Sun's] area, except the very darkest, were great masses of intensely brilliant hydrogen, evidently under great pressure. The sodium lines were extremely broadened, and on November 20 a broad bright flame of hydrogen was seen shooting up at an immense speed from one edge of the nucleus. A similar effect—an outburst of intensely luminous hydrogen—has often been observed in spots which have been accompanied by great magnetic storms; and it may even be that it is this violent eruption of intensely heated gas which has the directest connection with the magnetic auroral disturbances here upon Earth." (Maunder, 1900, p. 282).

4. Magnetic Disturbance

Continuous, ground-based monitoring of the Earth's magnetic field performed at fixed geographic locations or "magnetic observatories" (e.g., Love, 2008) has long informed scientific understanding of a variety of geomagnetic variation over time, some originating within the Earth and some originating in the Earth's surrounding space environment, including magnetic storms (e.g., Barraclough et al., 1992; Good, 1988). At first, these observatories reported "by-eye" spot measurements of geomagnetic direction and intensity made by Observatory staff on a regular or semiregular schedule. In the middle of the nineteenth century, observatories began to operate self-registering analog systems (e.g., Schröder & Wiederkehr, 2000). The design of these systems (Brooke, 1847; Ronalds, 1847) was ingenious (e.g., Peres et al., 2012): In a darkened room, light beams were projected onto tiny mirrors mounted onto magnetized needles that were suspended by delicate fibers. The needles aligned in response to the changing geomagnetic field and deflected the projection of the beam of light onto a piece of photographic paper that was mounted onto a rotating cylinder driven by a clock. Once a day, an observatory staff person would remove the photographic paper, develop it, and measure the light trace with a ruler. After conversion factors were applied, a time series of local geomagnetic variation could be reported. Magnetic observatories were operated in this way until the 1980s, when electronic sensors and digital acquisition systems became the new standard (e.g., Newitt, 2007).

Geomagnetic monitoring (as well as solar and meteorological monitoring) was supported at the Kew Observatory (King's Observatory) in London, England, from 1857 to 1924 (Scott, 1885). By the late nineteenth century, and under the Observatory's Superintendent, George M. Whipple (Unknown, 1893), Kew developed into an important center supporting magnetometer development and facilitating geomagnetic monitoring around the world. Beginning in 1857 (Stewart, 1860), the Observatory operated a self-registering magnetograph that was designed (e.g., Robinson, 1982) by Sir Francis Ronalds (Hartog, 1897) and John Welsh (Hartog, 1899) and built by the London instrument maker Patrick Adie (e.g., Unknown, 1886); see Figure 3. The "Kew-pattern" magnetograph was widely regarded as extremely effective, and it was used for geomagnetic monitoring at other observatories. One such place was the Colaba Magnetic Observatory. Established in colonial Bombay in 1841 by the East India Company (e.g., Gawali et al., 2015), the Colaba Observatory has long served as an important source of low-latitude geomagnetic data. Its Superintendent from 1865 to 1896 was Charles Chambers (Unknown, 1896), who had previously worked at the Kew Observatory. In 1870, a Kew-pattern magnetograph was installed in Colaba, and automatic analog recording of geomagnetic variation began at Colaba in 1871 (e.g., Gawali et al., 2015).

The United States Coast and Geodetic Survey (CGS) purchased a Kew-pattern magnetograph in 1860, but, with the outbreak of the American Civil War, the magnetograph was put into storage until 1878, when it was unpacked, tested, and found to be in good working order (Baker, 1883b). At about this time, plans were being made for the first International Polar Year (1882–1883) for which the United States would dispatch two teams to the north, one to Barrow, Alaska, and one to Lady Franklin Bay, Ellesmere Island, Canada (e.g., Barr et al., 2010, p. 94), to make various scientific observations and measurements. In complement to geomagnetic measurements to be made in the north, the leadership of the CGS decided to set up a magnetic observatory far to the south but still within U.S. territory—they chose a site in what was then the small town of Los Angeles, California (Baker, 1883b; Halter, 1888), a site, it turns out, where Los Angeles City Hall is now located (geographic 34.05°N, 241.76°E; 1882 geomagnetic: 40.88°N, 57.01°E). Marcus Baker (McGee, 1905) was appointed Assistant in Charge of the Los Angeles Observatory—he would later serve as editor of topographic and geologic maps for the U.S. Geological Survey and, then, go on to be a cofounder of the National Geographic Society (Dall, 1904). Los Angeles Observatory operations commenced in October 1882, just in time to record the November storm; a photograph of the magnetograph is shown in Figure 4. Baker (1883a) reported on the November storm: "Auroras are exceedingly rare phenomena in southern

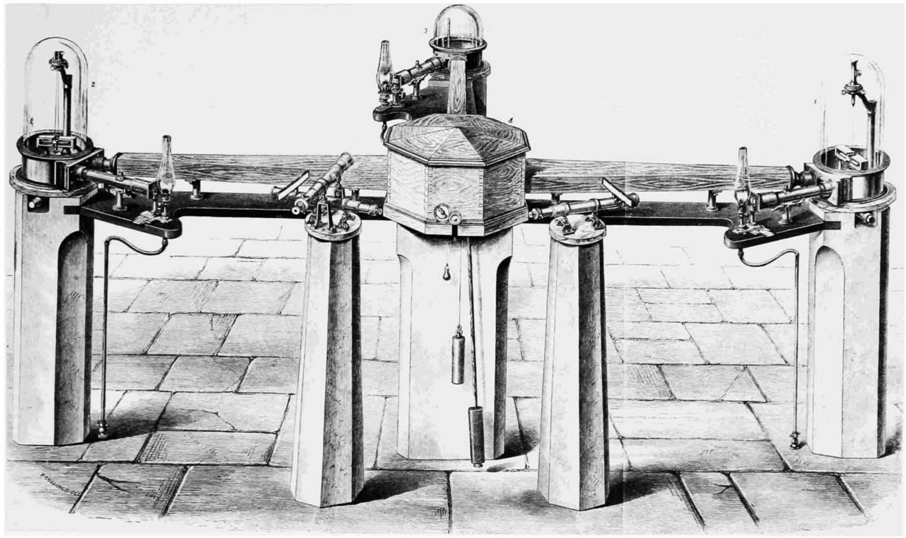

Figure 3. A schematic drawing of the Kew-pattern self-registering magnetograph system built by Adie (Gordon, 1880).

California; yet we had the pleasure of witnessing one on Nov. 17, at which time a great electric storm raged over North America and Europe. The photographic traces [obtained at the Los Angeles Observatory] during the storm … preserved a perfect record of the twitchings and jerkings, large and small, fast and slow, to which the magnets were subjected during this time."

The Los Angeles magnetogram for the November 1882 storm (Schott, 1893) is shown in Figure 5. Here we see that the storm commenced at about 02:20 local time on 17 November (10:12, 17 November 1882; Royal Observatory, Greenwich, 1955, p. 75) with a sudden impulse having a positive amplitude of about 70 nT (the photographic record, here, is faint on account of the rapidity of field change). Today, we understand that this sudden commencement would have been caused by the compression of the magnetopause with the arrival at Earth of a shock in the solar wind that, itself, was, almost certainly, related to an Earth-directed coronal mass ejection that came from the large sunspot some 2 days earlier. From local time 03:20 to 14:30, there followed a long duration of vigorous geomagnetic disturbance; Whipple described "the oscillations of the magnet and changes of force" as "incessant and frequently enormous, the declination needle ranging at times through almost 2°" (Christie, 1882). This period of disturbance would have corresponded to

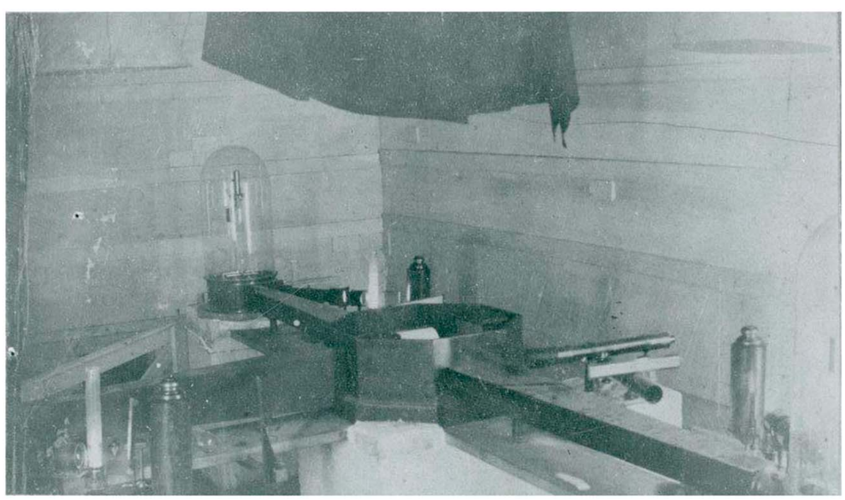

Figure 4. A photograph of the Kew-pattern magnetograph system in place in the Los Angeles observatory. Note that the lid on the recording box has been removed, showing the recording cylinder inside. Credit: NOAA archive.

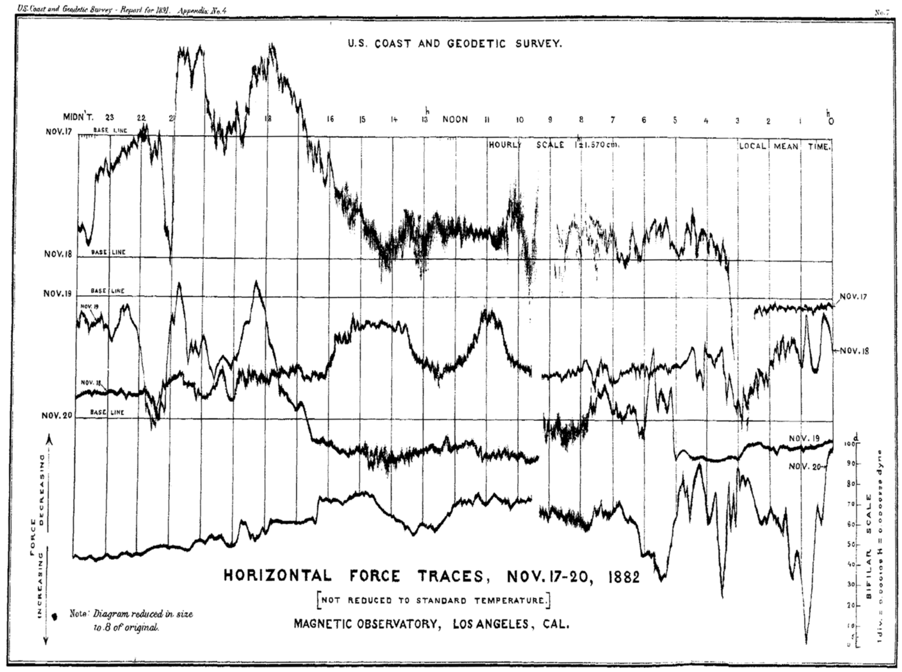

Figure 5. Magnetogram recording the November 1882 magnetic storm obtained by the Los Angeles Magnetic Observatory. Note that positive disturbance is down, and time is read from right to left.

abrupt rearrangements of magnetospheric field lines and substorm diversion of field-aligned currents into and out of the ionosphere from the magnetopause and magnetotail, causing the auroral illumination of nighttime skies at high and middle latitudes in North America and Europe.

Concerning anecdotes of the effects of the storm, the Chicago Daily Tribune (dated 18 November 1882) reported that widespread disruption of telegraph systems began at about 04:00 local time on 17 November; this would have been about 02:00 Los Angeles time and about when the storm commenced. In France, interference with telephone communication began at 10:30 local time (de Lalagade, 1882); if we assume that this is defined by the longitude of Paris, the corresponding time in Los Angeles would be 02:30 or just 10 min after the storm commenced. Earth currents on transatlantic telecommunication cable of the Anglo-American Telegraph Company were noticed when a worker arrived at his Ireland office at 10:55 in the morning (Graves, 1883). In Japan, interruptions to telegraph systems began at 20:57 local time (Ishie, 1883); if this is defined by longitude of Tokyo, then the corresponding time in Los Angeles would be 03:45 or about an hour and a half after the storm commenced and also during the phase of the storm exhibiting vigorous geomagnetic disturbance.

The storm's main phase can be identified by a characteristic diminution of horizontal intensity caused by an intensification of the magnetospheric equatorial ring current; this is seen in the Los Angeles magnetogram from local time 14:30 and onward for about 3 days. At local time 20:30 on 17 November 1882 (04:23, 18 November 1882, Greenwich) the Los Angeles magnetogram records a 1 h average low in horizontal intensity corresponding to a local storm time decrease of 470 nT. The Colaba magnetogram for this storm and corresponding numerical values for this storm can be found in Moos (1910) (volume 1, plate 81A; volume 2, pages 452, 457, 486), though (confusingly) with three different timestamps; judging time relative to the storm's sudden commencement, we estimate a 1 h average local main phase decrease of 299 nT. After applying latitude adjustments (Sugiura & Kamei, 1991) and averaging, we can estimate that this storm attained a maximum –*Dst* of 386 nT. By this measure, the November 1882 storm was about as intense as the "Halloween storms" of 29–31 October 2003 (383 nT). In comparison, and in terms of the *Dst* index, the storm of 13–14 March 1989 (589 nT) that brought down the Hydro-Québec power grid system in Canada (e.g., Allen et al., 1989), the storm of 15 May 1921 (Kappenman, 2006), and the "Carrington event" of 2 September 1859 (Siscoe et al., 2006; Tsurutani et al., 2003) were each more intense than that of 17 November 1882.

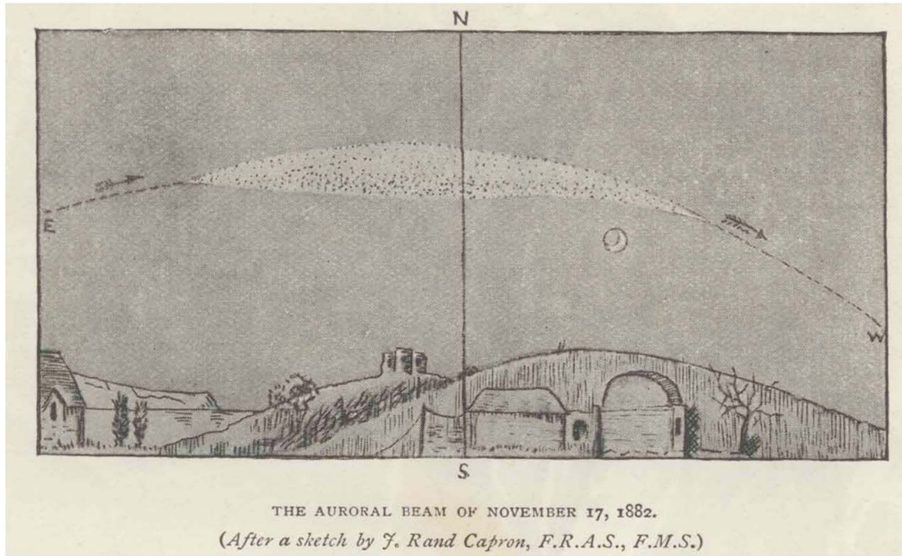

Figure 6. A drawing of the auroral beam seen by Capron and others on 17 November 1882 (Capron, 1883, p. 319).

The *aa* index is a global measure (Mayaud, 1972) of the range of geomagnetic variation typically realized over 3 h intervals of time at midlatitudes and derived from data collected at nearly antipodally located observatories in Britain and Australia. The *aa* index is the longest standard measure of historical geomagnetic activity, extending from 1868 to present. The (universal time) daily average of *aa* is the index *AA*. By this measure, the November 1882 storm was not as intense as the 1921, 1989, and 2003 storms. But the average *aa* level of geomagnetic disturbance, taken over a 4 day duration of time, was 214.25 nT, and in this respect, the persistent disturbance exhibited by the 1882 storm is the highest realized since 1868, for comparison: 1921 (182.73 nT), 1989 (175.05 nT), and 2003 (187.77 nT).

5. Mysterious Beam of Light

The auroral display that accompanied the magnetic storm of November 1882 included a peculiar sight that was reported by observers in southern England, Belgium, and parts of France, including by expert scientists. Among them was John Rand Capron, an English amateur scientist, Fellow of the Royal Astronomical Society, and pioneer in auroral spectroscopy (Unknown, 1889). He published a detailed summary of what he and others saw on the night of 17 November 1882. “About 6 P.M., while the aurora was fitfully blazing in the north, north-east, and north-western sky, in the east there rose from the horizon a long beam of detached bright light, which, apparently lengthening as it advanced, crossed rapidly the southern horizon in front of or near the moon, and then sank in the west, shortening in length as it did so” (Capron, 1883, p. 319); see Figure 6.

Capron continues: “The light emitted from it was described by one observer as of a glowing pearly white; and the general effect of this huge shining mass sailing majestically across the sky, even upon those accustomed to kindred phenomena, was at least one of wonder and surprise, while in the less experienced in such matters it created a feeling of absolute awe. Indeed to such an extent in some instances did this latter emotion prevail, that two labourers in my neighbourhood, who separately witnessed it, thought ‘that surely the world was coming to an end.’”

At the Greenwich Observatory, E. Walter Maunder recorded seeing red “coronae borealis” on 17 November, with light appearing to stream down from near zenith, and “pale-green light fringing the upper edge of the London smoke cloud.” Maunder and his observatory colleague, Frank Finch, noted a “magnificent streak of light”—it seems, the same one seen by Capron—rising in the “east-north-east” that “seemed to follow a parallel of declination, passing just above the Moon”, sinking with an “even regular motion down to the west” and taking “about two minutes to cross the sky.” (Royal Observatory, Greenwich, 1884, p. lxxv).

The auroral beam was evidently distinctive. But even though experienced astronomers documented its occurrence, Silverman (2006) speculates that it was a “sporadic” aurora, a definitive explanation for its cause has not, as far as I can tell, ever been offered. Perhaps the most that can be said, now, long after the manifestation of the 1882 auroral beam, is that unusual auroral sights might be seen during extremely intense magnetic storms. Indeed, the literature records other mentions of “unusual aurora” by seemingly experienced observers. (e.g., Howard, 1893; McLeod, 1930; Trudelle, 1916).

6. Solar-Terrestrial Interaction

The electric-magnetic storm dissipated by 22 November. Its ultimate cause, the sunspot, passed out of sight over the Sun’s western limb on 25 November. It was seen (again) coming over the eastern limb on 10 December but of diminished size. By 21 December the sunspot had faded away. New sunspots would emerge, and magnetic storms, some very intense, would occur again. And while smallish storms would sometimes occur when few, if any, sunspots were present, a statistical correlation between the two phenomena had been established years earlier (Sabine, 1857). In examining records of three “great sunspot displays” and “simultaneous” occurrence of three great magnetic storms (including that of November 1882), Maunder (1892, p. 91–93) remarked: “Is there any escape from the conclusion that the two have a real and binding connection? It may be direct, it may be indirect and secondary only, but it must be real and effective.”

What was not understood, at the close of the nineteenth century, was what this “binding connection” could be (e.g., Cliver, 1994; Good, 1988; Serviss, 1883). Theories were proposed, including “corpuscular” theories that resemble modern understanding of the solar wind (e.g., Fitzgerald, 1892), but when the (influential) Lord Kelvin (1893) calculated that magnetic waves emanating more or less uniformly from the Sun were unlikely to be of sufficient strength to cause magnetic storms at the Earth, some wondered whether or not the correlation between sunspots and magnetic storms might just be a “coincidence.” The subject was further complicated by Airy’s conclusion that at least part of the magnetic disturbance measured at observatories was due to the Earth currents that were affecting telegraph systems (Airy, 1868).

7. Modern Perspective

Today, it is understood that magnetic storms originate with the Sun; they can be caused by concentrated and semicontinuous streams of solar wind flowing from holes in the solar corona (where there are no sunspots) and, also, by sudden ejections of solar wind from the vicinity of sunspots—but the most intense storms are caused by coronal mass ejections (e.g., Tsurutani & Gonzalez, 1997). The interaction of the solar wind with the coupled system of the magnetosphere-ionosphere causes the transient magnetic disturbance that is a storm. Geomagnetic disturbance, in turn, induces geoelectric fields in the Earth’s electrically conducting interior, and the resulting geocurrents generate their own magnetic fields that add to the geomagnetic variation measured at a ground level observatory.

Whereas the magnetic storm of November 1882 caused widespread disruption of telegraph and telephone systems, more recently, magnetic storms, such as that of March 1989 (Allen et al., 1989), have adversely affected modern electric power grid systems (e.g., Béland & Small, 2005; Bolduc, 2002; Boteler, 2001). Some scenario analyses anticipate that the future occurrence of a rare magnetic superstorm could cause long-lasting, continental-scale loss of electric power (e.g., Abt Associates, 2017; Kappenman, 2012; Lloyd’s of London, 2013) and carry significant negative economic consequence (e.g., Baker et al., 2008; Barnes & Van Dyke, 1990; Eastwood et al., 2017). For this reason, the United States National Science and Technology Council (2015) and Committee on Space Research of the International Council for Science and the International Living with a Star (Schrijver et al., 2015) initiatives have identified the evaluation of geoelectric hazards as a priority pursuit.

Acknowledgments
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