Duration and Extent of the Great Auroral Storm of 1859

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ABSTRACT

The great geomagnetic storm of August 28 through September 3, 1859 is, arguably, the greatest and most famous space weather event in the last two hundred years. For the first time observations showed that the sun and aurora were connected and that auroras generated strong ionospheric currents. A significant portion of the world's 200,000 km of telegraph lines were adversely affected, many of which were unusable for 8 hours or more which had a real economic impact. In addition to published scientific measurements, newspapers, ship logs, and other records of that era provide an untapped wealth of first hand observations giving time and location along with reports of the auroral forms and colors. At its height, the aurora was described as a blood or deep crimson red that was so bright that one "could read a newspaper by." At its peak, the Type A red aurora lasted for several hours and was observed to reach extremely low geomagnetic latitudes on August 28-29 (~25 º) and on September 2-3 (~18º). Auroral forms of all types and colors were observed below 50º latitude for ~24 hours on August 28-29 and ~42 hours on September 2-3. From a large database of ground-based observations the extent of the aurora in corrected geomagnetic coordinates is presented over the duration of the storm event.

INTRODUCTION

Great auroral events, as noted by *Chapman* [1957], are those rare events that are observed in the geomagnetic latitude range from 45º N to 45º S and occur near sunspot maximum. At the peak of the auroral events of August 28-29 and September 2-3, 1859 the aurora were brilliantly red and were reported as visible from within 23º of the geomagnetic equator in both northern and southern hemispheres from observations collected by *Kimball* [1960] and as we will report in this paper, the aurora were seen to even lower latitudes. In addition to the scientific measurements that where published, newspapers of that era provide an untapped wealth of first hand observations giving us time and location along with reports of the auroral forms and colors. Once recognized, auroral displays where big news for both small local and metropolitan newspapers. If the weather was clear during an auroral display, you could almost guarantee a story in the local news the next day or even a few days later. Newspapers reports of the great aurora rarely got into the scientific journals but they are valuable observations that are included in this study. In addition, this study will also use US government ship deck logs taken at sea (or in port) that provide additional independent observations of the aurora at low latitudes.

Previous reports [c.f. *Editors*, 1859; 1860a; b; c; *Loomis*, 1860a; b; 1861a; b; 1865; *Kimball*, 1960] have cataloged many of the scientific observations with some analysis of the extent of the aurora but there was little analysis on the duration of the aurora within the context of the total event extending from August 28 through September 5th. The purpose of this paper is to show the time evolution in corrected geomagnetic coordinates of the great geomagnetic storm of 1859 utilizing a large collection of first hand accounts and observations published and many other reports not previously cataloged. Newly uncovered observations show that the auroral displays on September 2-3 were observed to lower latitude than previously reported.

SEQUENCE OF EVENTS

On September 1, 1859, Richard Carrington and Richard Hodgson, while observing a large sunspot group independently, were the first to observe a white light flare [*Carrington*, 1860; Hodgson, 1860]. Both observers also noted the nearly simultaneous Solar Flare Effects (SFE) seen in ground-based magnetometers from currents arising from enhanced ionospheric ionization. Within ~17 hours later the Earth experienced the massive auroral display of September 2-3 from a coronal mass ejection (CME). The Great Storm in 1859 occurred about 10 months prior to the peak of the sunspot number, but that was not an unusually strong peak, only about 98. Of the 33 cycles since 1700, there have been 16 that have peaked higher. This indicates that the sun is capable of producing solar wind conditions (e.g. CME) necessary to produce a comparable auroral event during almost any solar cycle.

The database developed for this study contains observations of aurora, magnetometer, and telegraph station information and was complied from scientific reports [primarily *Editors*, 1859; 1860a; b; c; *Loomis*, 1860a; b; 1861a; b; 1865] (periodicals and books), newspaper accounts, ship logs, other manuscript reports, and the catalogs created by *Kimball* [1960] and *Silverman* [see *Hills*, 1998]. The auroral observations used in this study must contain three major elements. They have to provide a start and stop time of the aurora along with the location of the observation and a description of the auroral form or color. There are literally several hundred reports that the authors have uncovered that could not be used since they typically do not report a start and stop time of the observed aurora. Since aurora are produced by precipitating particles carrying field-aligned currents that close in the ionosphere, magnetic fields generated by these currents can be measured by ground-based magnetometers and induce currents in telegraph systems. As discussed earlier, for the great storm of 1859, these ionospheric currents were so strong that magnetometers frequently went off scale and telegraph systems became inoperable. These observations where included in this study since they provide strong indirect evidence that the aurora was nearby even during the daytime. Once again, start and stop time of these events and location were necessary.

Each panel in Figure 1 is a geographic mercator projection of data for one-hour time spans of the northern hemisphere for the August 28-29. Figure 2 is the same for September 2-3. The blue lines are the corresponding geomagnetic dipole latitudes. Figure 1 is populated with orange dots marking the location of the auroral observations and blue dots the magnetometers stations. The poleward (yellow) and equatorward (orange) auroral boundaries from the Holzworth-Meng model [*Holzworth and Meng*, 1975] have been added to show the extreme lower latitude auroral zone boundary. It is important to note that the equatorward boundary uses a Q-index of 60 in which a Q-index of 11 is the largest recorded over the last 40 years. Although use of Q-index of 60 is not a valid input to the model it is the only way we can obtain some idea of where the auroral zone might be located. In the second panel from the top of Figure 2, close to the height of event on September 2 the auroral zone from the extrapolated

Holzworth-Meng model is within 8° of the magnetometer observations in Bombay, India. Movies have been generated of the entire database, in a similar format as Figure 1 and Figure 2, and are posted at: http://rpi.gsfc.nasa.gov/~boardsen/auroral_movies_1859

[Note to reviewers and Editor: A permanent web location for the database and the movies in the National Space Science Data Center archive will be arranged when the article has been accepted].

The database used in this study contains all the information the authors have been able to find in the 1859 event no matter where the location of the observations comes from (for example there might be several papers that describe the aurora observed in New York City). The only filter that is used is that each observation must contain information that can uniquely describe the time of the observation (i.e.; "at sunset", "at 8PM", "lasting till midnight", "continued till sunrise"). It is important to note that 1859 was well before the adoption of a standard time system and that variations of an hour can easily exist. All efforts were made to map the reported observation time to universal time, which is then used throughout this study. As a default, reported times were assumed to be "local time" unless specifically noted in the report. The fact that the observed aurora existed for many hours greatly facilitates this analysis making the data set look more uniform than it probably is, as shown in Figure 3. In addition, nearly all of the observations are not precise beyond 30 to 60 minutes as reported.

All auroral observations used in this study are plotted in Figure 3 by the absolute value of their corrected geomagnetic latitude versus the derived universal time (ranging over 8 days around the event) using the 1900 model coefficients in the international geomagnetic reference field (IGRF) model [see for example: *Campbell*, 1997]. The IGRF 1900 model coefficients are the closest to 1859 that have been published, and are the most authoritative magnetic field model that can be used (we did not extrapolate the coefficients back to 1859). Corrected geomagnetic coordinates are important for accurate mapping of the observations.

Since this event is very near equinox it is reasonable to add both the northern and the small number of southern hemisphere data together. The long black bars show that the auroral sightings were made over significant portions of the night and over an extensive range in geomagnetic latitudes, the blue bars are from telegraph stations and the orange bars from ground magnetometer stations.

The data in Figure 3 are all ground-based observations that by their very nature must be made on a cloudless night. The unique data in Table 1 are from US government ship logs stored in the archives of the National Archives and Records Administration (NARA) and provide the data containing the lowest latitude observations of the aurora. The NARA Record Group (RG) 24 contains records from the Bureau of Naval Personal while RG27 are records from the Weather Bureau. Clearly, regions on the globe were very cloudy accounting for gaps in coverage. Many of the US government ships were in harbors at various locations in Japan and did not see the aurora, however, we have an observation of a red aurora being observed in northern Japan at the same time [*Nakazawa et al.*, 2004]. To compensate for times of clouds an "envelop" or probably maximum extent for the aurora is given in Figure 3 as a dashed line. The actual variation is not known but it is expected that it would be below this envelope at any one time. Also shown is the Bombay magnetometer station data that *Tsurutani et al.* [2003] claim is measuring the ring current.

Nearly all the reports during the time of the two maximum auroral expansions to the lowest geomagnetic latitudes were for the brilliantly bright red (Type A) aurora. A vertical strip pattern appears in Figure 3 that is a direct result of the majority of observations coming from English speaking countries when they are on the nightside. Some observations of the aurora in Russia and Asia (Japan was mostly cloudy during the event) and from ship logs fill in this gap and lead us to the conclusion that the aurora was observed steadily for many hours at a time over very large regions as indicated by the latitudinal envelop of the aurora drawn in Figure 3.

DISCUSSION

The appearance and dissipation of the ring current, as measured by Dst, is the basic definition of a geomagnetic storm. A typically geomagnetic storm lasts for a day or more. The process of onset, expansion, and recovery of high latitude aurora during a geomagnetic storm is defined as a substorm. During a geomagnetic storm, multiple substorms (auroras) are nearly always observed.

Since the white light flare that *Carrington* [1860] and *Hodgson* [1860] observed on September 1 is believed to be the initiator of a CME that reached the Earth on September 2-3 [*Tsurutani et al.*, 2003] it is therefore, most likely, that the two major auroral storms on August 28-29 and again on September 2-3 as shown in Figure 3, are from two closely spaced interplanetary CME's reaching the Earth very close together. The interaction of a fast CME plowing through a slower CME has been observed [*Gopalswamy et al.*, 2001] and produces a stronger shock. This effect may be partially responsible for the extreme nature of the September 2-3 auroral event. It is for these reasons that this study has loosely referred to these two major auroral substorms as part of one geomagnetic storm.

Many of the high latitude ground-based magnetometer data are unusable since the auroral currents were so strong that they went off scale. Recently, *Tsurutani et al.* [2003] reanalyzed the ground-based magnetometer observations at Bombay India. The main conclusion reached by that study was that the Bombay magnetometer, on September 2-3, was primarily observing the ring current and that it reached a phenomenal Dst of –1760 nT at the beginning of the event. The long red bar in Figure 3, on September 2 near 10^{o} corrected magnetic latitude, shows the total time interval of the reported Bombay magnetometer Dst observations. As shown in Figure 3, the large negative Dst values of the Bombay magnetometer occurred during a time of rapid equatorward expansion of the aurora to the incredibly low geomagnetic latitudes (as observed on the nightside) of ~18^{o}. Ground-based auroral electrojet magnetometer measurements of –1760 nT, although large, are much more in line with what is measured from auroral currents than the ring current. Based on these results, the Bombay magnetometer was most likely measuring magnetic field perturbations from currents in the nearby auroral electrojet and the magnetopause, in addition to the ring current with the nearby auroral electrojet potentially dominating the measurements.

CONCLUSIONS

Since the weather was mostly clear over many of the inhabited areas of the Earth, over the several days of the storm, an enormous number of people observed the aurora. A brilliant Type A red aurora was visible for several hours to the lowest latitude during August 28-29 and again on September 2. The aurora was observed to reach extremely low geomagnetic latitudes on August 28-29 (~25°) and on September 2-3 (~18°). With the results presented in this paper, it is expected that the next steps in understanding this event can now be realized through computer modeling and simulations. Figure 3 can now be used by the modelers to simulate the whole event since magnetospheric conditions depends on a time history of solar wind input conditions.

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Ship	Date	Local Time	Latitude	Longitude	Reference
Release	August 28	8 to Midnight	39° 11′N	72° 07′	RG24
Savannah	August 28	8 to Midnight	37° 24′N	65° 51′W	RG24
Arcole	August 28-29	8PM-morning	41° 40′	46° 45′	RG27
Savannah	August 29	Midnight to 4	36° 09′N	64° 11′W	RG24
Saranac	August 29	Till 4 AM	Panama		RG24
Release	September 2	Midnight to 4	35° 32′N	60° 14′W	RG24
Messenger	September 2	By 1AM	49° 09′	67° 28′	RG27
Arcole	September 2	4AM	41° 16′	27 ° 12′	RG27
St. Mary's	September 2	12:00 AM	12° 23′00″N	88° 28′00″W	RG24
Sabine	September 2	12:30 AM	11° 14′19″N	83° 49′30″W	RG24

Table 1: Extraction of key information from the ship deck logs during the great geomagnetic storm of 1859.

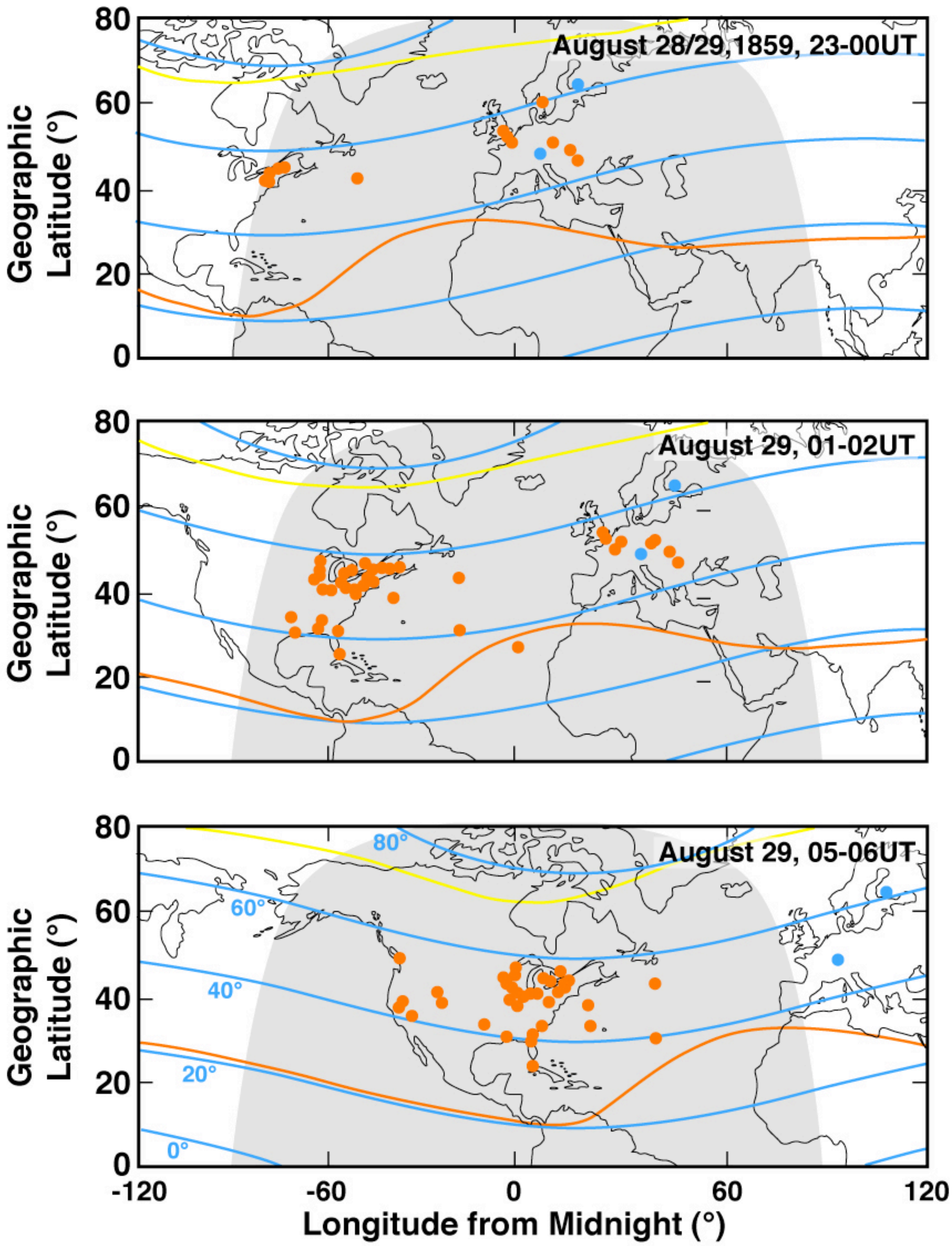

Figure 1: Location of eyewitnesses accounts (orange dots) and magnetometer stations (blue dots) of the great aurora on August 28, 1859 for selected times as a geographic mercator projection in the northern hemisphere centered at local midnight. Geomagnetic dipole latitude is shown as blue wavy lines with the yellow and orange lines the minimum and maximum extent of the auroral oval from Holzworth-Meng model, respectfully.

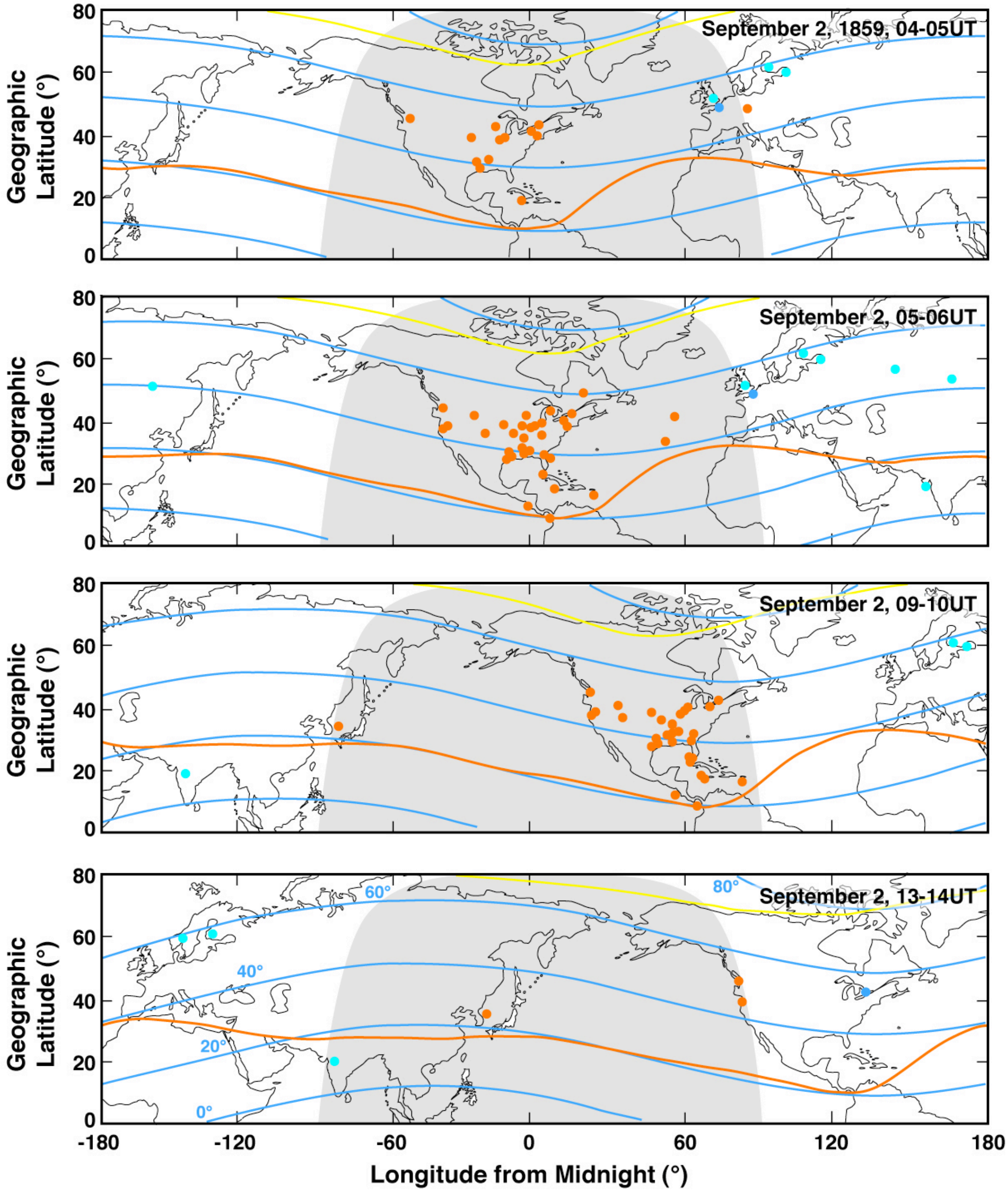

Figure 2: Same as Figure 1 except for September 2-3, 1859 over the northern hemisphere with each panel centered on midnight.

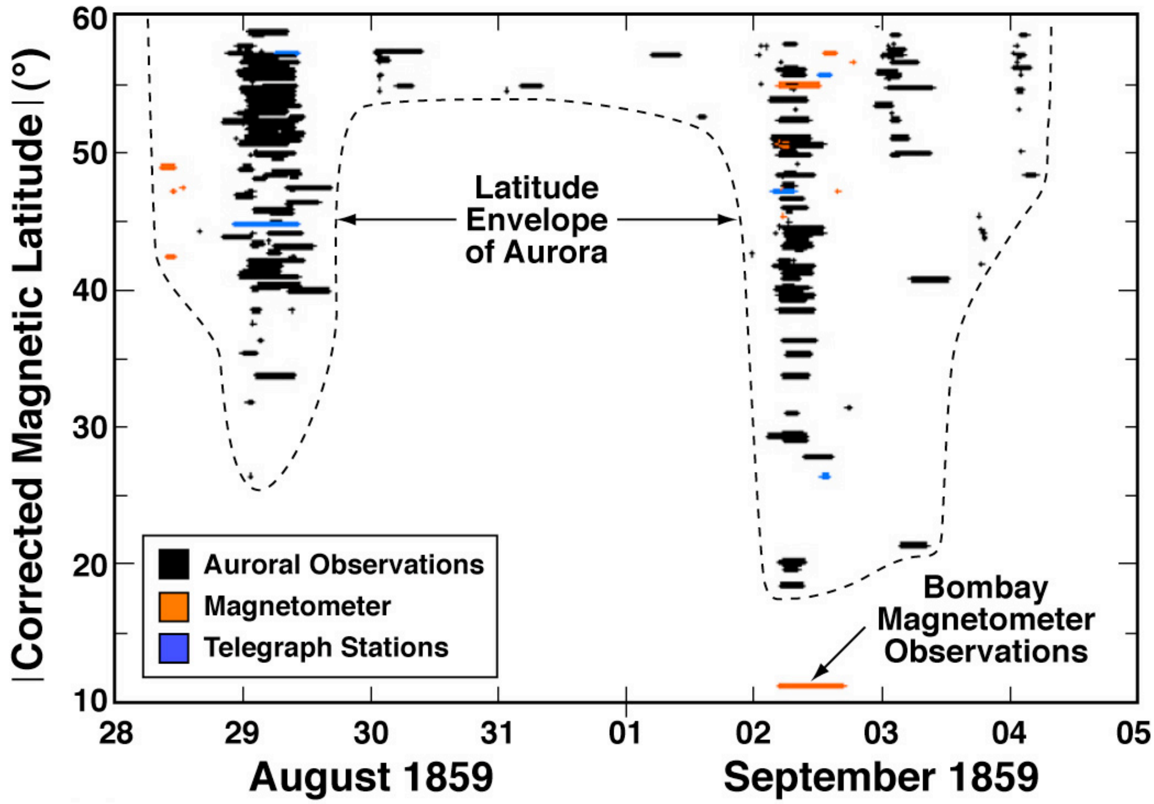

Figure 3: The absolute value of the corrected geomagnetic coordinates of each entry in the database as a function of Universal Time from August 28th through September 5, 1859.