VERY INTENSE MAGNETIC STORMS IN 1841-1870 REGISTERED BY THE RUSSIAN GEOMAGNETIC NETWORK

N.G. Ptitsyna, M.I. Tyasto, B.A. Khrapov

St. Petersburg Filial of the Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation, Russian Academy of Science, (SPbFIZMIRAN), 191023, St. Petersburg, Russia, email: nataliaptitsyna@ya.ru

Abstract. Our report poses the problem of the use of the Russian historic geomagnetic data for the purposes of space weather. The Russian network of geomagnetic observatories was constructed in 1830, when regular measurements in Yekaterinburg, Barnaul, Nerchinsk, Nukus, Sitka and Beijing (connected to the Russian embassy) were added to the magnetic measurements already performed in St. Petersburg. In this work we present an analysis of very intense magnetic storms registered in 1841-1870 by these observatories. We considered great geomagnetic storms with magnitudes that approximately correspond to Dst < -200 nT (or Kp ≥ 8). A catalog of very intense magnetic storms has been constructed. The catalog contains initial moments of the storm, the most disturbed day (periods) and the storm’s duration common for all Russian observatories. Maximal ranges of magnetic field components H and D and Z for St. Petersburg and information on solar and geomagnetic activity are given. Statistical characteristics of intense magnetic storms during considered period are found. For our collection of storms it is found only one peak in solar cycle which falls into years of maximal activity (or little earlier). We have found two-fold increase of great storms in solar maxima (or little earlier) in comparison with periods of lower activity. Such distribution is characteristic for the storms which are associated with interplanetary magnetic clouds. Yearly distribution of 1841-1870 storms shows a peak in September-October and a secondary peak in February. It is found an inverse dependence of the storm intensities from their duration. The giant storm on 2 September, 1859 of short duration approaches the very end of the tail of the distribution.

Introduction

Eruptive activity of the Sun produces a chain of extreme geophysical events, in particularly, geomagnetic storms that form an important component of space weather. Intense geomagnetic storms can potentially destroy spacecrafts, kill astronauts and adversely affect airline crew and human health on the Earth.Geomagnetic storms produce induced currents (GIC) in ground-based long conductors such as power lines, pipelines and railway systems. GIC lead to pipeline breaking, melt electricity transformers, discontinue transmission, stop trains and generally wreak havoc with human activities. Studying of extremes of geomagnetic disturbances will help in understanding and forecasting space weather. However data for very intense magnetic storms are limited. Only one super-intense storm has been recorded (Dst=-640 nT, March 13,1989) during the space-age (since 1958). Research on historical data can help to create a more comprehensive database for intense and super-intense magnetic storms. In this paper we have analyzed intense geomagnetic storms registered during 1841-1870 by the Russian network of geomagnetic observatories: St. Petersburg, Yekaterinburg, Barnaul, Nerchinsk, Nukus and Sitka. In addition, we have used magnetic field measurements in Beijing which were done for some years in the Russian embassy. The results of the measurements at the network of these stations were regularly published in the form of annuals and formed substantial part of scientific knowledge at that time together with the works of the Russian magnetologists.

Data

In this work, we use the data of magnetic observations of the geomagnetic field H, D and Z-components performed from 1 January, 1841 to 31 December 1870 performed by the Russian network. There were no data for 1863-1869. The geomagnetic observatories were the following: Sankt Petersburg (geographical φ=59.9°, γ=27.9°E), Yekaterinburg (φ=56.8°, γ=58.25°E), Barnaul (φ=53.3°, γ=81.6°E), Nukus (φ=42.4°, γ=59.6°E), Nerchinsk (φ=51.3°, γ=117.25°E), Beijing (φ=39.9°, γ=116.3°E), and Sitka (φ=57.2°, γ= -135.4°W). The data are hourly measurements. For some disturbed periods 5-min data were also available.
It is difficult to use archived magnetic measurements because, in particular, the discrepancies were revealed between the magnetic value and time units indicated in the publications and the units accepted in the present. In addition, the data in the Annuals are presented in the form of relative units, which should be converted into absolute units by using the field absolute value which were not given in Annuals. This required an additional analysis [Tyasto, 2009]. In addition, M. Rykachev [1899], the third director of GFO, complained that many errors were encountered in The Annals of the Kupfer time (before the magnetic observatories were included in the Academy of Sciences in 1865). Therefore, the mechanical usage of the annuals can result in errors. We did a special analysis for revealing possible errors, assessing calibration and accuracy of measurements. Moreover, we determined the correspondence between the magnetic units and time standards used in mid-19th century and accepted at present.

Results

Our analysis was based on the daily tenpoint index (CP9) obtained for St. Petersburg magnetic observatory [Zosimovich, 1981] similarly to the international index C9 [Chapman and Bartels, 1940]. Different index values (from 0 to 9) characterize magnetic disturbance depending on the algebraic difference ($R$) between maximal and minimal deviations of magnetic elements during a day from smoothed normal diurnal variations. Here geomagnetic storms with $C9_r \geq 8$ which approximately correspond to $Dst < -200$ nT (or $Kp = 8$ and 9) [Loewe and Prölls, 1997] were considered. We have found 16 severe geomagnetic storms during aforesaid period. They are presented in Table 1.

Table 1. Great geomagnetic storms during 1841-1870.

<table>
<thead>
<tr>
<th>№</th>
<th>Year</th>
<th>Start day, month</th>
<th>Start hour UT</th>
<th>max</th>
<th>$\Delta T$ hour</th>
<th>RH nT</th>
<th>RD Degree,min.</th>
<th>RZ nT</th>
<th>C9</th>
<th>W</th>
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<tr>
<td>1</td>
<td>1841</td>
<td>24. 09</td>
<td>17</td>
<td>25.09</td>
<td>64</td>
<td>&gt;771</td>
<td>1 16,33</td>
<td>638</td>
<td>9</td>
<td>36,5</td>
</tr>
<tr>
<td>2</td>
<td>1847</td>
<td>24.09</td>
<td>01</td>
<td>24.09</td>
<td>40</td>
<td>&gt;1043</td>
<td>1 56,24</td>
<td>-</td>
<td>9</td>
<td>160,9</td>
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<tr>
<td>3</td>
<td>1847</td>
<td>23.10</td>
<td>06</td>
<td>23.10</td>
<td>30</td>
<td>&gt;816</td>
<td>1 23,63</td>
<td>-</td>
<td>9</td>
<td>180,4</td>
</tr>
<tr>
<td>4</td>
<td>1847</td>
<td>24.10</td>
<td>12</td>
<td>24.10</td>
<td>56</td>
<td>&gt;854</td>
<td>0 48,43</td>
<td>-</td>
<td>9</td>
<td>180,4</td>
</tr>
<tr>
<td>5</td>
<td>1848</td>
<td>20.02</td>
<td>21</td>
<td>21-22.02</td>
<td>53</td>
<td>784</td>
<td>1 04,52</td>
<td>-</td>
<td>9</td>
<td>111,8</td>
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<tr>
<td>6</td>
<td>1848</td>
<td>17.11</td>
<td>08</td>
<td>17-18.11</td>
<td>80</td>
<td>&gt;660</td>
<td>1 27,92</td>
<td>-</td>
<td>9</td>
<td>114,6</td>
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<tr>
<td>7</td>
<td>1851</td>
<td>06.09</td>
<td>21</td>
<td>07.09</td>
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<td>899</td>
<td>1 25,91</td>
<td>-</td>
<td>9</td>
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<tr>
<td>8</td>
<td>1852</td>
<td>19.02</td>
<td>09</td>
<td>19.02</td>
<td>31</td>
<td>&gt;819</td>
<td>1 46,69</td>
<td>-</td>
<td>9</td>
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<tr>
<td>9</td>
<td>1859</td>
<td>28.08</td>
<td>09</td>
<td>28-29.08</td>
<td>52</td>
<td>&gt;462</td>
<td>0 42,82</td>
<td>-</td>
<td>8</td>
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<tr>
<td>10</td>
<td>1859</td>
<td>02.09</td>
<td>04</td>
<td>02.09</td>
<td>5</td>
<td>&gt;980</td>
<td>3 08,48</td>
<td>-</td>
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<tr>
<td>11</td>
<td>1859</td>
<td>02.09</td>
<td>11</td>
<td>02.09</td>
<td>21</td>
<td>&gt;700</td>
<td>1 23,72</td>
<td>-</td>
<td>9</td>
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<tr>
<td>12</td>
<td>1860</td>
<td>05.07</td>
<td>0</td>
<td>05.07</td>
<td>45</td>
<td>663</td>
<td>0 52,90</td>
<td>-</td>
<td>9</td>
<td>116,7</td>
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<tr>
<td>13</td>
<td>1862</td>
<td>02.10</td>
<td>15</td>
<td>03-04.10</td>
<td>54</td>
<td>716</td>
<td>1 27,97</td>
<td>-</td>
<td>9</td>
<td>41,9</td>
</tr>
<tr>
<td>14</td>
<td>1862</td>
<td>06.10</td>
<td>04</td>
<td>06.10</td>
<td>32</td>
<td>587</td>
<td>0 39,66</td>
<td>-</td>
<td>8</td>
<td>41,9</td>
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<tr>
<td>15</td>
<td>1870</td>
<td>24.10</td>
<td>07</td>
<td>25.10</td>
<td>28</td>
<td>513</td>
<td>2 03,1</td>
<td>436</td>
<td>8</td>
<td>146,4</td>
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<tr>
<td>16</td>
<td>1870</td>
<td>25.10</td>
<td>11</td>
<td>26.10</td>
<td>33</td>
<td>457</td>
<td>1 27,9</td>
<td>&gt;378</td>
<td>8</td>
<td>146,4</td>
</tr>
</tbody>
</table>
The catalogue contains information on year, month, day and hour of initial moments of storms, the most disturbed day (periods) and the storm’s duration ($\Delta T$) common for all Russian observatories. Maximal range of magnetic field components H and D (for some cases also Z), peak-to-peak value $R$ of magnetic field components and geomagnetic index $C9$ for Sankt Petersburg ($C9_P$) are given. In addition, solar activity index $W$ (sunspot number) is presented.

On Fig. 1-3 examples of great historic storms registered by the Russian network are shown.

**Fig. 1.** Magnetic field variations (H and D) registered on 20-23 Feb., 1848 at St. Petersburg (red) and Sitka. a) H-component, b) D-component. Variations are taken from an arbitrary level as in original tables.

**Fig. 2.** H-component variations on 18-21 Nov 1852. The right ordinate axis is related to Ekaterinburg, Barnaul and Nerchinsk. Variations are taken from an arbitrary level as in original tables.
In Fig. 1 and 2 we present hourly measurements done in different observatories of the Russian network during very disturbed periods on 20-23 Feb., 1848 and on 18-21 Nov 1852. It is seen good agreement of the data.

Fig. 3. H-component variations on 2 September 1859 in St. Petersburg (red) and Yekaterinsburg (Blue, right ordinate axis). Measurements were taken every 5 min.

In Fig. 3 the famous superstorm on 2 September 1859 registered by the Russian geomagnetic network is shown. The measurements were taken every 5 min. The storm occurred 18 hours after the first ever registered in white light solar flare on 2 Sep 1859, the Carrington flare. Magnetic readings went out of scale in all stations except Colaba (India), where geomagnetic disturbance value led to estimations of $D_{st} = 1760$ nT ([Tsurutani et al.,2003]).

Next, the relationship of great geomagnetic storms with solar activity and their yearly distribution have been studied. Distribution of storms in solar activity cycles is presented in Fig. 4.

Fig. 4. Great storms and solar activity (Wolf numbers W) in 1841-1870.

Our results show that high solar activity played a key role in generating very intense magnetic storms. We have found two-fold increase of great storms in solar maxima (or little earlier) in comparison with periods of lower activity. Very intense storms show only one peak in solar cycle which falls into years of maximum of activity (or little earlier).
Yearly distribution of the storms shows maximum in September - October and another much lower maximum in February (not shown here).

In Fig. 5 we show dependence of the storm intensities from the storm duration. It is seen that intensity of storms decreases with the increase of the storm duration. Correlation coefficient between RD and $\Delta T$ is rather high $K=-0.56$. The giant storm on September 2, 1859 ($\#10$ in our catalogue) presents the extreme point of the distribution. It is characterized by very high intensity and short duration. However even this extreme storm is in the area of found distribution.

**Summary of results and conclusion**

In this work we performed a retrospective analysis of the observations of the geomagnetic field $3$ components, which were conducted from January 1, 1841 to December 31, 1870, at magnetic observatories St. Petersburg, Yekaterinburg, Barnaul, Nercinsk, Nukus, Sitka and Beijing. This period covers 8-11 solar cycles. It was difficult to deal with the historical data, but we overtook these difficulties. As a result of our analysis a catalog of very intense magnetic storms during 1841-1870, has been constructed. We considered geomagnetic storms with $C9_p \geq 8$, which approximately correspond to $Dst < -200$ nT (or $Kp = 8$ and 9) [Loewe and Prölls, 1997]. The catalogue contains initial moments of the storm, the most disturbed day (periods) and the storm’s duration $\Delta T$ common for all Russian observatories. Maximal ranges of magnetic field components H and D (for some cases also Z) for Sankt Petersburg and available information on solar and geomagnetic activity are given. This catalogue was used to study statistical features of very intense storms occurred in 8-11 solar cycles (1841-1870). We have found the following features of considered storms:

- A peak in September-October and a secondary peak in February in yearly distribution of storms
- An inverse dependence of the storm peak-to-peak value $R$ from its duration $\Delta T$. The giant storm on September 2, 1859 presents an extreme point of the found $R-\Delta T$ distribution
- Only one peak in solar cycle which falls into years of maximum of activity: magnetic storms in years around solar maximum were double that those in less active periods. Such distribution is characteristic for the storms which are associated by interplanetary magnetic clouds.

Thus we arrive to a conclusion that high solar activity plays a critical role in generating very intense storm in 1841-1870.

The results of our analysis indicate that the data from all Russian stations are in good agreement. Therefore, we can conclude that the historical magnetic measurements at Russian observatories are reliable.
These data are of special importance because the measurements at all stations were performed using identical instruments and the same methods [Kupfer, 1855; Rykachev, 1899].

Our catalogue expands database of very big storms to period 1841-1870, when there were not planetary indexes of geomagnetic activity (note that aa index covers the activity only from 1868).

References

Kupfer A. T., Instructions Governing Magnetic and Meteorological Observations, Compiled by a Director of the Main Physical Observatory for Magnetic Observatories of the Mining Department, 2nd ed., Addition to the Code of Observations for 1852 (Korp. Gorn. Inzh., St. Petersburg, 1855) [in Russian].