An Assessment of Pc5-Like Pulsations Observed During the Carrington Storm

Session 2, Poster 11: Recent Advances in Space Weather Science

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Introduction

The Greenwich and Kew (both London) observatory magnetograms for 1st and 2nd September 1859 show prolonged periods of ULF Pc5-like pulsations, most likely global Pc5 driven by the solar wind during the recovery phase of the storm. Unlike the very high amplitude variations that are off scale during the peak of the magnetic storm on 1st September 1859 (see Figure 1), the pulsation events have apparently been well preserved in the records of the time. (Further information on and images of the 'Carrington event' magnetograms for the UK can be found at www.bgs.ac.uk/data/Magnetograms/home.html.)

We have therefore tried to put the measured amplitude and duration of the UK Carrington Pc5 pulsations into some context by analysing them in relation to modern day records. For this we have analysed Pc5 pulsations occurring in data from the Hartland observatory, which is geographically relatively close to London, and Wingst observatory, Germany. Wingst, in particular, has a geomagnetic latitude believed to be closer to that of Kew and Greenwich at the time of the Carrington storm (around 50 degrees north). There are complete records from the early 1980s to the present day, providing a continuous data set containing many severe storms from the recent past for comparison.

By means of various Pc5 measures (e.g. amplitude, duration, root-mean-square over the day, and others) we have tried to determine how atypical the Carrington pulsations were.

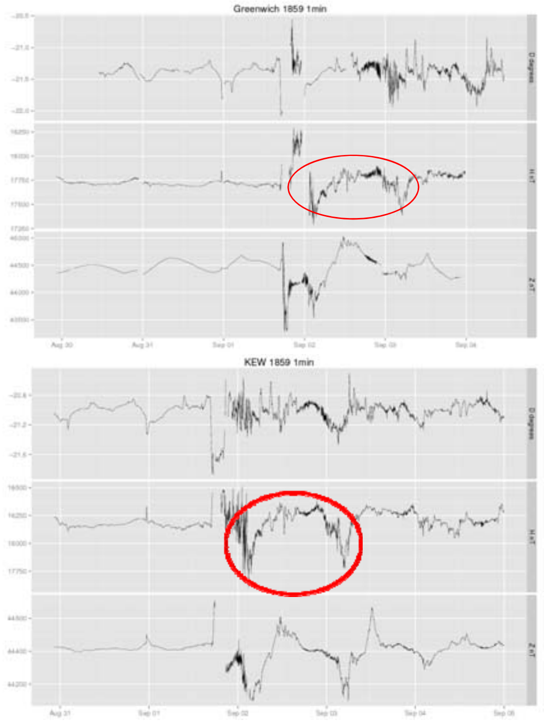

Figure 1. Magnetic data for the London magnetic observatories scanned and digitised manually, with the help of a software tool ('Engauge'), for the Carrington Event of 1859. Some periods of strong Pc5-like pulsations in the horizontal component (H) are highlighted. Note that, as labelled, the timing is inconsistent: the sudden impulse that appears to be just before the start of September 1st is known to be at 11:15 GMT on the 31st August. This is a consequence of the 12 hour difference between astronomical and civil time. Absolute values of the field were determined from the known (published) amplitude of the sudden impulse (delta-H=110nT, delta-D=0.283 degrees).

Related Reading

1. Nevanlinna, H (2005), A Study on the great geomagnetic storm of 1859: Comparisons with other storms in the 19th century, Advances in Space Research 38, 180-187.
2. Thomson, A., Dawson, E., Reay, S. (2011), Quantifying extreme behaviour in geomagnetic activity, Space Weather, Vol. 9.
3. Love, J. J., E. J. Rigler, A. Pulkkinen, and P. Riley (2015), On the lognormality of historical magnetic storm intensity statistics: Implications for extreme-event probabilities, Geophys. Res. Lett., 42, doi:10.1002/2015GL064842.

Method

The Carrington paper magnetograms for the London observatories at Greenwich and Kew were digitised using the 'Engauge' software tool (Figure 1) and sampled at a one minute cadence. One-minute digital data for Hartland (UK) and Wingst (Germany) for 1983 to 2014 were also obtained. We then filtered these data in the Pc5 2.5-10 minute pass-band by means of an 8th-order Butterworth filter. (We also looked at data in other neighbouring pass-bands from five minutes to fifteen minutes period duration, as a form of 'sensitivity analysis' of the results to the quality of the digitisation. Though we don't show these other results here, they were consistent with the results we do show.)

We then investigated the relative strength of Pc5 pulsations, per day, by the following measures: root-mean-square; peak absolute amplitude; time-integrated mean-square; and time-integrated absolute amplitude. Examples are shown in Figure 2 for Wingst. By calculating similar data for the few days of the Carrington event (1st to 3rd September 1859) we can then compare the relative magnitude of this historic storm, in this pass-band.

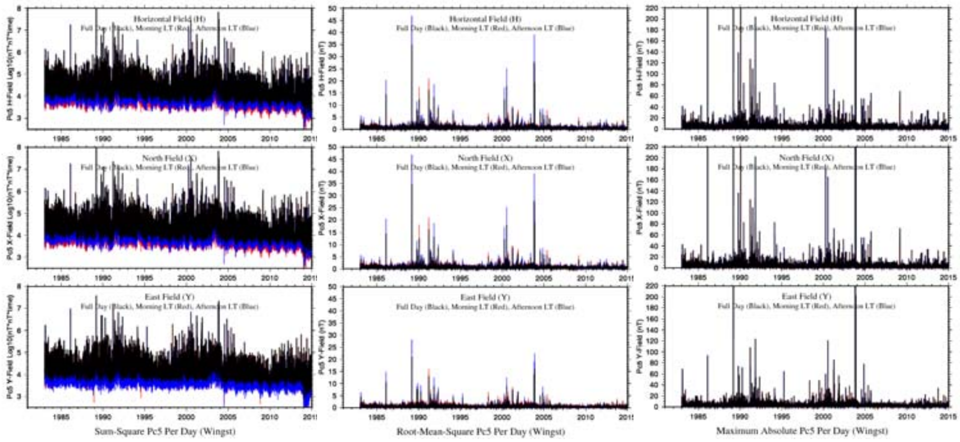

Figure 2. Different measures of the strength of Pc5 pulsations from 1983 to 2014 for Wingst. The H, X (North) and Y (East) components are shown and data are either one value per day (black) or one value separately for morning (red) and evening (blue) local times. There are some LT differences not considered here. Note that the vertical scales are chosen here to help highlight smaller variations, i.e. not just identify the peaks. Note also that the noise floor in the 'sum-square' plot decreases over time, possibly indicating improvements in magnetometer or measurement technology.

Results

In the Table below we compare Greenwich and Kew Carrington 'RMS-Pc5-Day' (c.f. middle plot of Figure 2) with Wingst and Hartland data for recent ≥10nT storms at Wingst (1983-2014). Values are nT.

Storm: Year/Day	Greenwich	Kew	Hartland	Wingst
1859/245	16.9	36.9		
1986/39			4.9	14.5
1989/72			18.7	35.0
1990/26			0.4	12.4
1991/83			10.9	16.3
1991/312			5.9	13.3
2000/97			4.8	12.3
2000/197			10.6	17.9
2003/302-304			15.0 (Day 302)	27.9 (Day 303)
2003/324			9.8	19.2

Carrington on this measure is broadly comparable to March 1989 and larger than October 2003. An initial **extreme value statistical (EVS) analysis of the Wingst data for 1983-2014 shows that the expected 'RMS-Pc5-Day' mean value for a one in 30/100/200 year event is approximately 28/35/38 nT. Therefore there is no upper limit, but the return level is not a strong function of return time.** Therefore in the EVS context the Carrington event still cannot be readily categorised as a many-decades or many-centuries event.

Summary, Conclusions and the Future

- Regardless of the measure used here, the Carrington event does not show up as a particularly extreme case, in terms of Pc5
  - Perhaps there is a physical reason for this?
  - Perhaps the EVS methodology needs refining (noting that the 95% confidence limits are large)?
- However we cannot be sure that this is actually a result of the relative insensitivity of 19th century magnetometers, in comparison with instruments in use in the last few decades
  - Ideally we would reconstruct a typical magnetometer of the Carrington era and run it in parallel with a modern instrument to provide a proper re-calibration of the Carrington data
  - But if this interpretation is correct then this would imply that other magnitudes in 19th century magnetograms, e.g. the peak rate-of-change of field, are likely underestimated, as the magnetometer responds relatively sluggishly to fast field changes. We may also underestimate peak delta-B
  - This interpretation also has implications for the interpretation of magnetic measurements during the Carrington Event at other observatories, by other instruments and observers
- And we cannot be sure that the amplitude of the historical Pc5 data are not influenced by the digitisation process itself
  - We can study any 'bias' by employing a number of independent (human) digitisers
  - But we have looked at slightly slower pass-bands, e.g. 10-15 minutes and results are not contradicted
- We therefore plan to investigate the data and magnetometer characteristics further