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Extremes in Worldwide Geomagnetic Activity

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Introduction

Geomagnetic storms pose a hazard to many modern technologies. Therefore understanding how severe such storms could be is important to a wide range of space weather data and forecast end-users. Extreme value statistical (EVS) methods are therefore applied to a global set of geomagnetic observatory data to determine the one in 100 and one in 200 year extreme values in the north, east and horizontal field strengths and their time rates-of-change. We use one-minute digital data from geographically widely distributed observatories with typically a few decades of digital operations. Individual generalised Pareto distribution functions are fitted to the tail of each observatory data distribution, above some threshold marking the onset of extreme activity for that location.

We discuss the return levels, for the one in 100 and one in 200 year events, with respect to the geographical distribution of the observatories, the proximity to auroral and equatorial electrojets and compare results with a separate EVS study of European-only magnetic observatory data [1].

Data

We use 1-minute digital data from 22 observatories held at the World Data Centre for Geomagnetism, Edinburgh, with as long a time series as possible, which have a wide geographical distribution (see Figure 1). The time spans range from 15 years (Argentine Island - AIA) to 38 years (Hermanus - HER).

For each observatory the data are carefully quality controlled, with spurious outliers (e.g. data spikes) removed. We then compute a time series of residuals (in H, X and Y) with respect to quiet levels, by removing the quiet mean level derived from the five 'International Quiet Days' in each month. This isolates the external field influenced by space weather.

We also calculate the rate-of-change in each component by computing first differences of minute means.

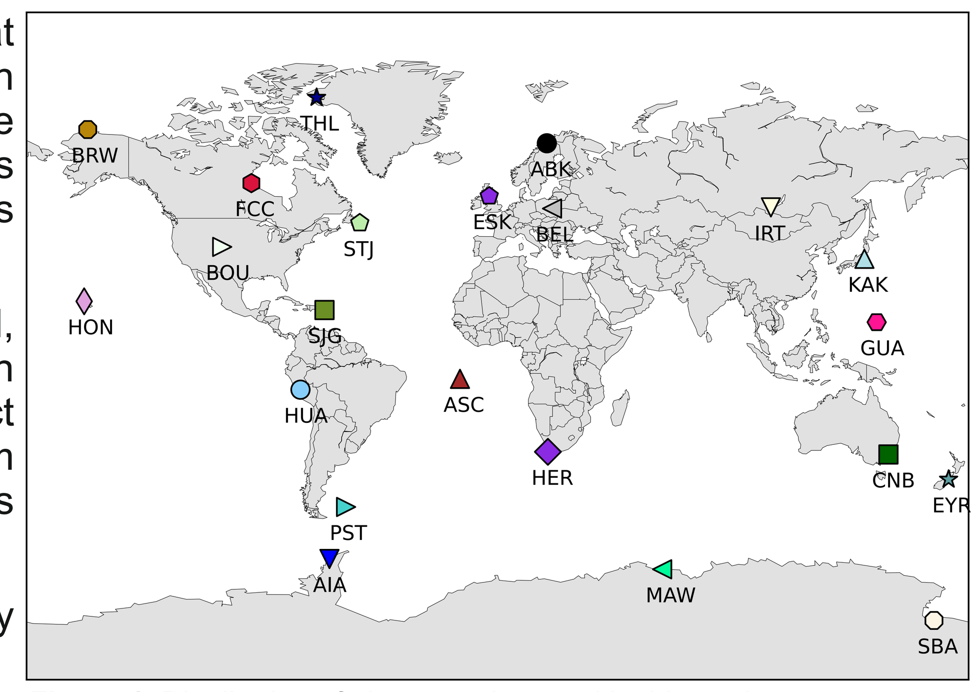

Figure 1. Distribution of observatories used in this study.

Extreme Value Statistics and Threshold Selection

We use a generalised Pareto distribution (GPD) to describe the tail of the distribution of geomagnetic activity (e.g. [2]). The GPD is a unifying description of the Gumbel, Frechet and Weibul distributions, widely used in the scientific literature when examining extremes in variables. The GPD is applicable to our data, as we have individual one-minute samples and some idea of an appropriate starting threshold of extreme geomagnetic activity. This is known as the 'point over threshold' approach.

The choice of threshold will necessarily be different at each observatory, as some places (i.e. high latitudes) observe much larger values than elsewhere. The ideal threshold should be low enough to allow for a meaningful number of samples, but high enough to identify extreme behaviour. To maintain consistency in our threshold selection we set the threshold at the 99.95 percentile for the residual data and 99.99 percentile for the rate of change data.

Clusters of extreme values occur during geomagnetic storms. As we wish to identify the return period for a major event, i.e. a single magnetic storm, we only include the maximum during the storm, as including any near-maxima would skew the result. We therefore only select events which are above the threshold and separated by at least 12 hours.

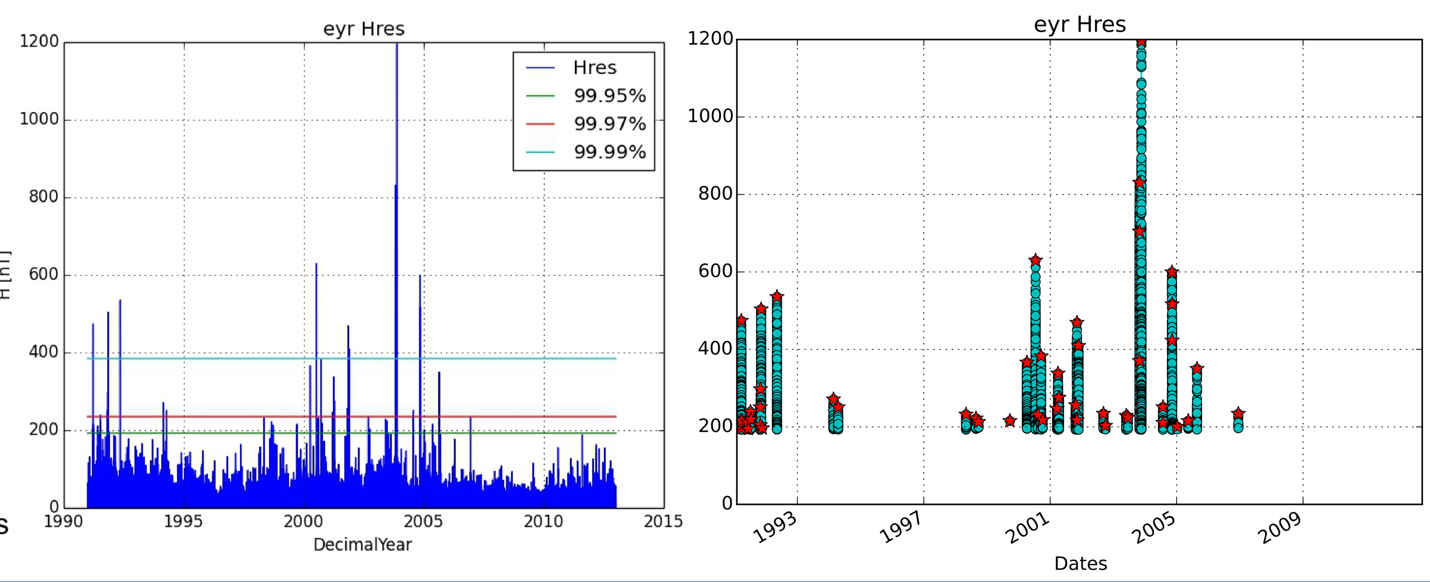

Figure 2. An example of the threshold selection (left) and the effect of declustering (right) at Eyrewell (EYR) observatory for the H residuals. The red stars on the right hand plot are the data that were selected, the blue circles are all values that were over the 99.95 percentile.

The data were analysed using the extRemes software toolkit [3] that runs on the R statistical analysis package [4].This provided us with return level plots, such as those shown in Figure 4, and other diagnostics.

In general the return level plots look like the example for Honolulu on the left of Figure 3, with the return level always increasing with return period. However, there are a few observatories for which the return level for some of the components appears to saturate (Figure 3, right), suggesting there may be an upper limit to geomagnetic activity.

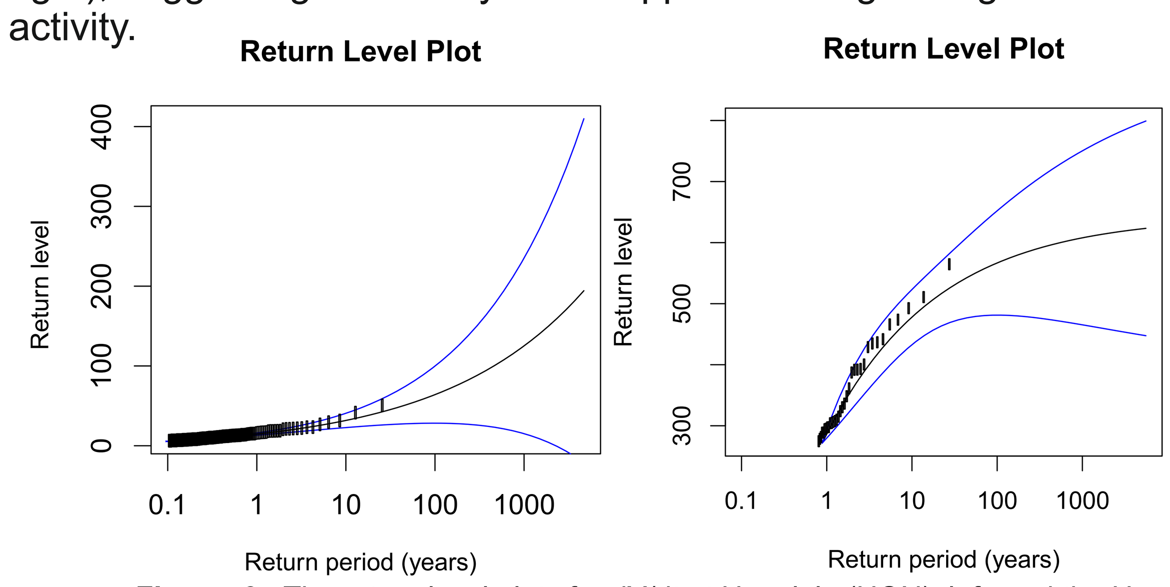

Figure 3. The return level plots for dY/dt at Honolulu (HON), left, and the H component at Guam (GUA), right.

Return Value Plots by Geomagnetic Latitude

When plotted against geomagnetic latitude we can see some interesting features in the return levels:

- The 100 and 200 year return levels are smallest at low to mid-latitudes.
- At low latitudes the return values are not much larger than the maximum values already observed there. The 95% confidence ranges are also smallest at low latitudes.
- The largest return values are for observatories between approximately 55° -70° geomagnetic latitude.
- The plots appear to show an asymmetry between northern and southern latitudes. However, this is likely due to a lack of observations in the southern hemisphere.

Table 1 shows that there is a wide numeric range of expected return values across observatories.

	100yr	200yr
H	517 - 5317	544 - 6431
dH/dt	71 - 3136	79 - 4930
X	194- 3730	230-4620
dX/dt	69 - 2930	77 - 4560
Y	469 - 5388	507 - 7397
dY/dt	20 - 2034	21 - 2394

Table 1. The range of return periods calculated across all 22 observatories. Units are nT and nT/min.

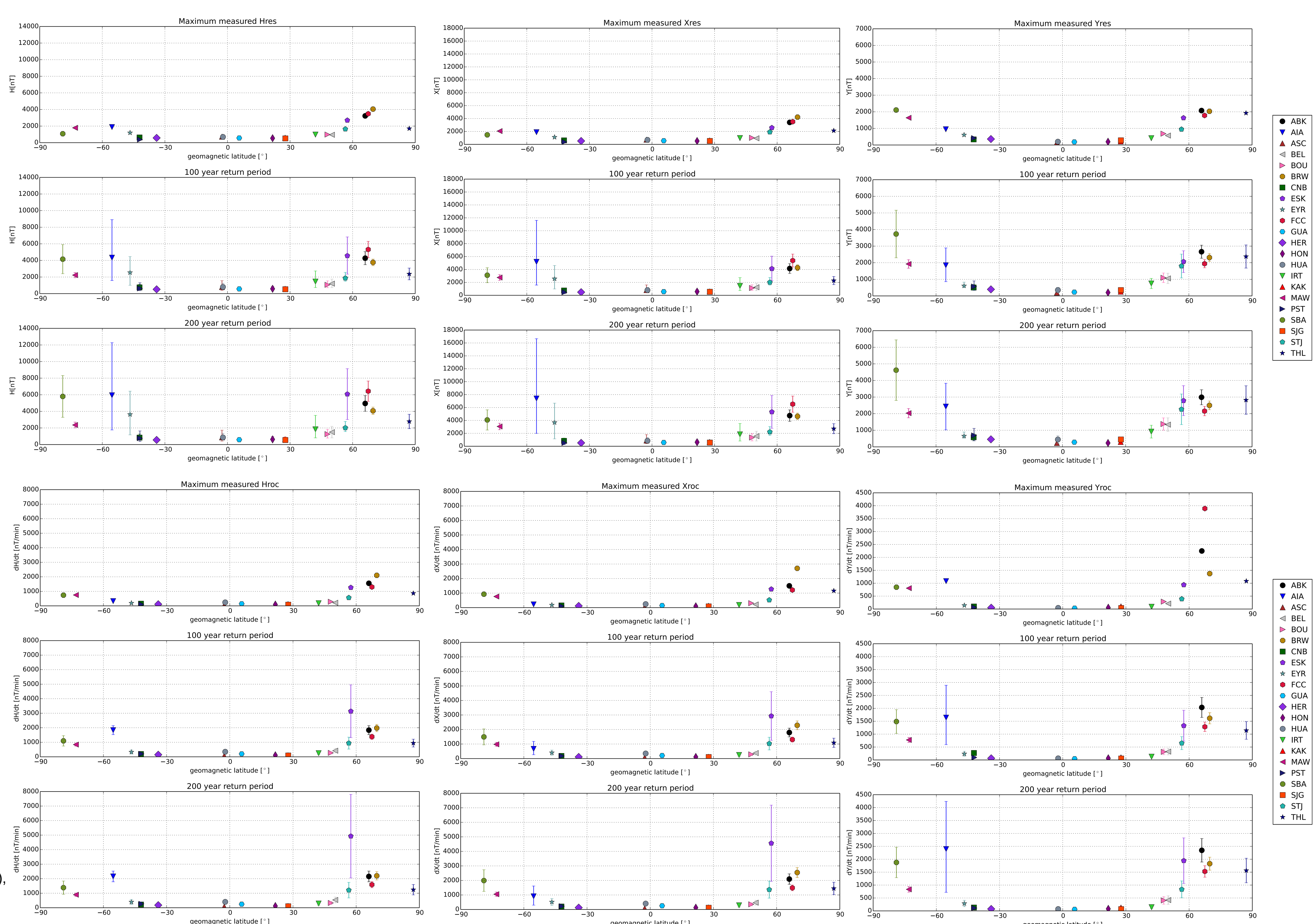

Figure 4. Maximum observed values and 100 and 200 year return values for each observatory, plotted against geomagnetic latitude, in H (left), X (middle) and Y (right), for the residuals (top row) and the rate-of-change (bottom row). The 95% confidence limits are shown.

Summary

- We have estimated the 100 and 200 year maxima in H, X and Y (and their rate-of-change) at 22 globally distributed observatories with a large time span of digital data.
- The largest return values are for those observatories between approximately 55° and 70°. This is consistent with the European-only study [1].
- The return values are also consistent with the European study, which (excluding a noted outlier, see [1] for more details) found a 100yr (200yr) maximum return value of around 5000nT (6500nT) in H and 4000nT/min (6000nT/min) in dH/dt.

Future Work

- More detailed investigation into the threshold selection - For some observatories this method of selection results in less than 1 or more than 10 "extreme" values per year which is not optimal for the GPD.
- Include more observatories, particularly at high latitudes and in the auroral zones.
- Investigate the apparent saturation in return levels at some observatories. It is often, but not exclusively, low latitude observatories that show this behaviour - does this mean there is a physical limit to how large a storm can be at some latitudes?

References:
1. Thomson, A. W. P., E. B. Dawson, and S. J. Reay (2011), Quantifying extreme behaviour in geomagnetic activity, Space Weather, 9, S10001, doi:10.1029/2011SW000696
2. Coles, S. (2004), An Introduction to Statistical Modelling of Extreme Values, Springer, London.
3. Gilleland, E and Katz, R. W., 2005. Tutorial for the Extremes Toolkit: Weather and Climate Applications of Extreme Value Statistics http://www.assessment.ucar.edu/toolkit.
4. R Development Core Team, 2008. R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, www.R-project.org