British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL


# Estimating the Extremes in European Geomagnetic Activity

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## Abstract

Rapidly changing geomagnetic field variations constitute a natural hazard, for example in navigation and, through geomagnetically induced currents, to power grids and pipeline networks. To understand this hazard we have continuous magnetic measurements across the world for typically less than 100 years. Much of the older data is also in analogue form, or is only available digitally as hourly or daily magnetic indices or mean levels. So it may not yet be clear what the true extremes in geomagnetic variations are, particularly on time scales - seconds to minutes - that are relevant for estimating the hazard to technological systems.

We therefore use a number of decades of one minute samples of magnetic data from observatories across Europe, together with the technique of 'extreme value statistics' to explore estimated maxima in field variations in the horizontal strength and in the declination of the field. These maxima are expressed in terms of the variations that *might* be observed once every 100 and 200 years. We also examine the extremes in one-minute rates of change of these field components over similar time scales.

The results should find application in both hazard assessment for technologies and in navigation applications. The results can also be used to more rigorously answer the often-asked question: "*just how large can geomagnetic storms and field variations be*?"

## 1. Extreme Value Statistics - Theory

We use a Generalised Pareto Distribution (GPD) to describe the tail of the distribution of geomagnetic activity (see e.g. Coles, 2004). The GPD is a unifying description of the Gumbel, Frechet and Weibul distributions, widely used in the scientific literature when examining extremes in variables.

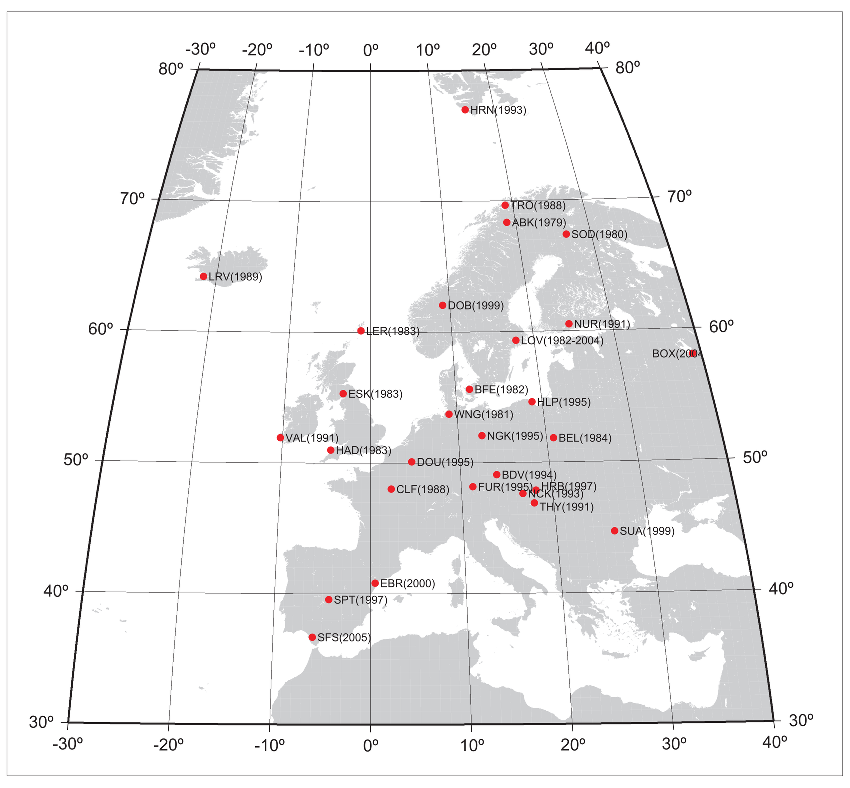
These three distributions can be shown to be limiting cases of a Generalised Extreme Value (GEV) function of three parameters, describing the location (L), scale (S) and shape (P) of a data distribution. GEV statistics are commonly used where only block maxima are available, e.g. annual maxima of daily temperatures. The GPD is more general still and 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. A simple example of a geomagnetic threshold might be the US Space Weather Prediction Centre's definition of 'severe magnetic storm', defined when *Ap*>100.

The GPD function is $\mathbf{G(x;S',P,u) = 1 - [1+P(x-u)/S']^{(-1/P)}}$ where $x-u>0$, $1+P(x-u)/S'>0$ and $S'=S+P(u-L)$, is given in terms of the equivalent parameters, L, S, P, from the GEV distribution.

G gives the probability of the random variable (here a field variation or residual with respect to some baseline), X, exceeding a high value, x, given that it already exceeds a high threshold, u, i.e. $\Pr[X>x|X>u]$.

There are subtleties in applying extreme value statistics to geomagnetic data, e.g. the need to de-cluster sequences of storm or sub-storm data following from one or more related coronal mass ejections and, in general, the non-stationarity of geomagnetic variations.Though these subtleties can be dealt with, we do not consider this point further in this initial study.

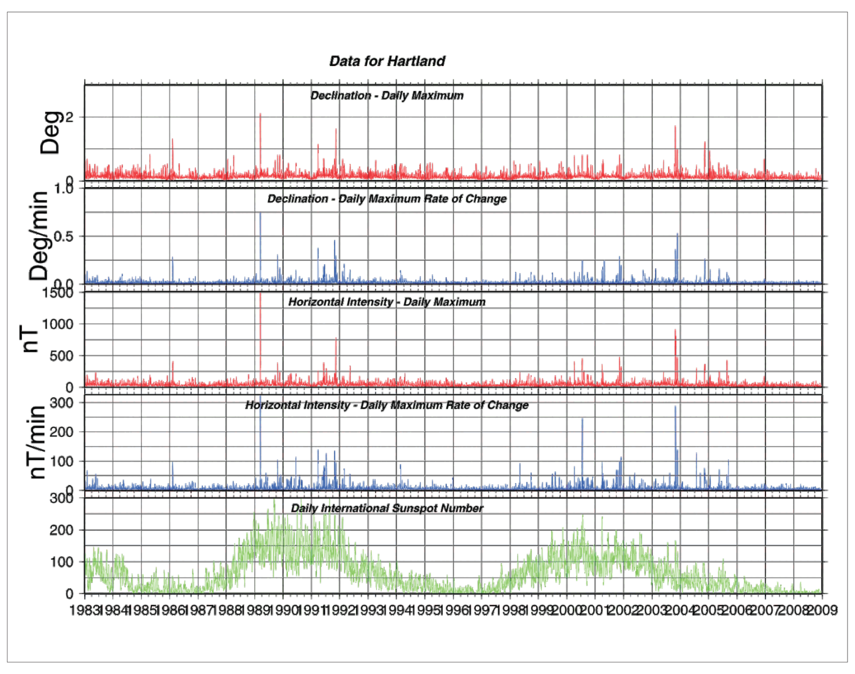
## 2. Extreme Value Statistics - Data & Methods



One minute geomagnetic data in *H* (horizontal field), *D* (declination), d*H*/dt and d*D*/dt (the latter two computed as one-minute differences) were obtained from the Edinburgh World Data Centre (www.wdc.bgs.ac.uk), for 29 European observatories (Figure 1).

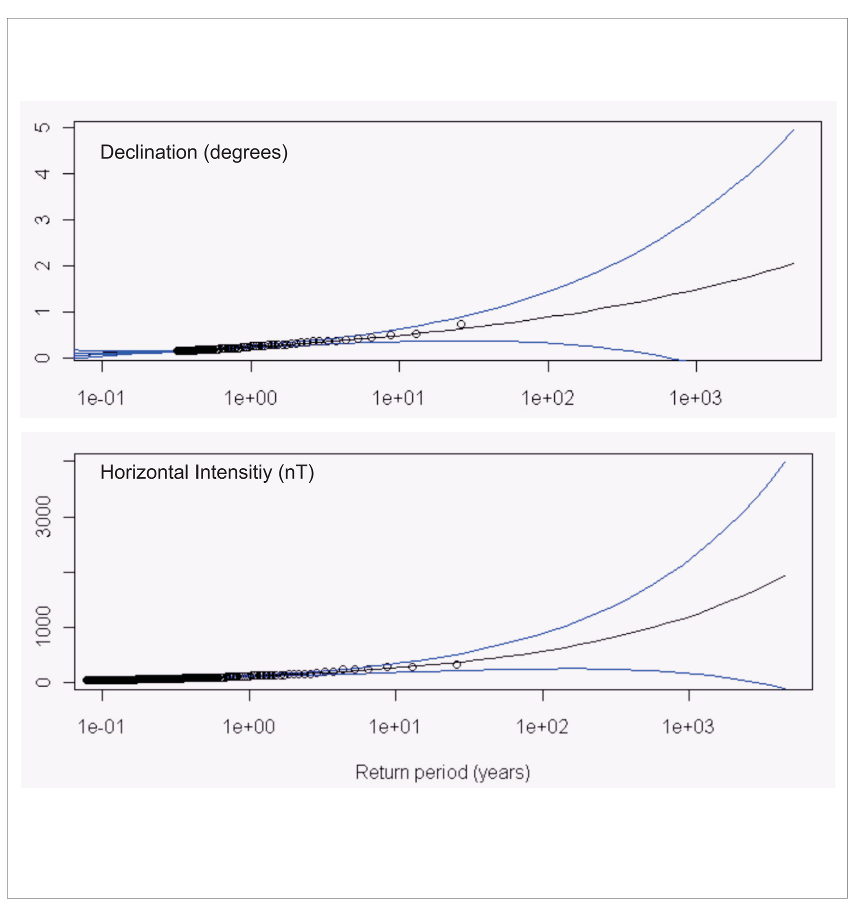
These observatories were chosen to provide a representative spread of measurement sites across the continent, including a range of magnetic latitudes and for which there are continuous data over a number of years.

**Figure 1.** European geomagnetic observatory data used in the analysis, annotated with the start year (from 1st January) of available one-minute data. End date is either (December 31) 2007 or 2008, depending on the observatory.




Variations (i.e. residual data), representing the external field only, were constructed for each observatory by removing a quiet mean level, established for each month from the five 'International Quiet Days' as determined by the International Service of Geomagnetic Indices. Absolute values of these variations were then computed (Fig. 2).

**Figure 2.** *H* (nT), *D* (degrees) residuals and one-minute rates-of-change for the Hartland mid-latitude observatory (one minute data, 1983-2008). Daily maxima of the absolute residuals are shown, as is sunspot number, to identify any solar cycle dependence.




The absolute variation data were analysed using the *eXtremes* software toolkit (Gilleland and Katz, 2005) that runs on the R statistical analysis package (R Development Core Team, 2008). Maximum one-minute values observed per 15-minute time block were used as our basic data set, providing a manageable reduction in database size, whilst permitting a reasonably 'fine-grained' analysis.

Component maxima were determined for both the time-span of data, and via the projected GPD distribution for periods of 100 and 200 years. 95% confidence levels were also determined. An example of a typical output from the *eXtremes* toolkit is given in Figure 3.

**Figure 3.** Return periods for observed Hartland *D* (upper) and *H* (lower) residuals (circles) and the fitted and extrapolated GPD (line) to each of *D* and *H*. Vertical scales are degrees and nT respectively; horizontal scale is time in years. The blue lines are the approximate symmetric +/-95% confidence limits from the fit of model to data, via an *eXtremes* function.

## 3. Extreme Value Statistics - Results

For each observatory and each component we have extracted the peak variation (i.e. residual) and rate-of-change predicted by the GPD to be exceeded for return periods of 100 and 200 years. To do this, appropriate geomagnetic activity thresholds (u) were determined for each observatory. These thresholds generally increase with geomagnetic latitude and are typically around 10% of the maximum observed in the observatory one-minute data. The results are summarised in Figure 4.

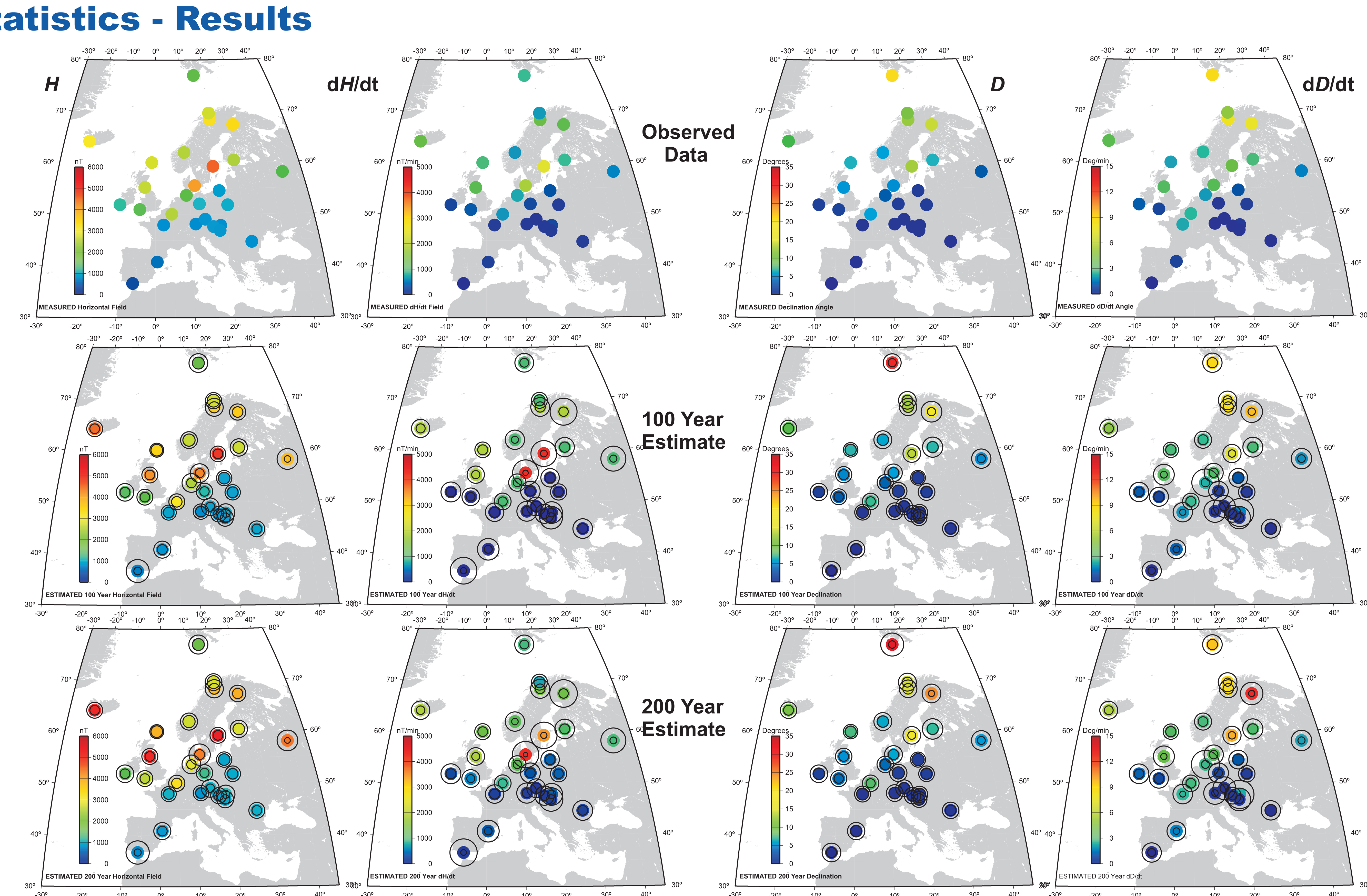



**Figure 4.** Top/Middle/Bottom - respectively the Measured/100-year-return-level/200-year-return-level, for *H* (left/1st column), d*H*/dt (2nd column), *D* (3rd column), and d*D*/dt (right/4th column). Units are nT, nT/min, degrees, degrees/min (left to right). More accurate asymmetric 95% confidence levels are the inner and outer rings around each coloured mean level.

Return levels are strongly influenced by the measured levels found in each observatory data set. There is, predictably, a dependence on geomagnetic latitude but also some 'regional structure' found around the North Sea, particularly in *H* and d*H*/dt.

## 4. Conclusions and Future Work

The results of this initial analysis are summarised in Figure 4 above. We find that predicted return magnitudes increase with geomagnetic latitude, although there is some other, as yet unexplained, structure in the data found around the North Sea. Future work will concentrate on testing some of the assumptions made in the analysis and then extending the analysis to observatories elsewhere in the world.

## Acknowledgements

We would like to acknowledge scientific institutes in Europe for providing their magnetic data via INTERMAGNET and the World Data Centres. Colleagues at BGS are also thanked for comments on this work.

## References

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