Is Kp=9o a useful classification of extreme geomagnetic storms when predicting potential damage to power grids?

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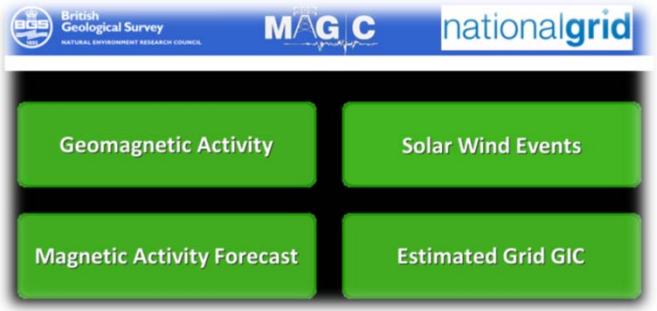
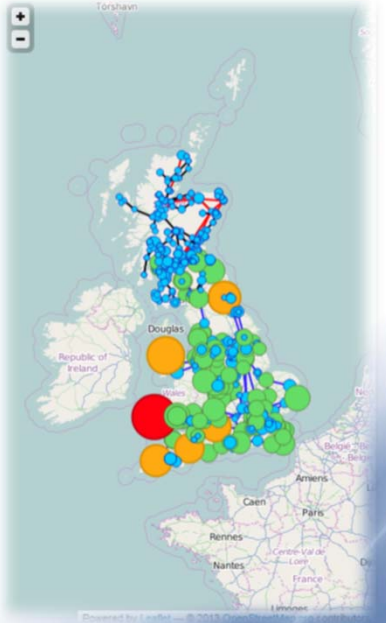
Geomagnetic storms and power grids

- Geomagnetic storms lead to Geomagnetically Induced Currents (GIC)
- These currents flow through power grids, pipelines, etc.
- GIC have the potential to cause damage to ground based technological infrastructure
- Operators need to understand the risk





NOAA G scales and Kp

- Widely used and recognised
- We use them to forecast and to categorise past activity
- Based on Kp, the 3-hourly geomagnetic index

BGS Global Geomagnetic Activity Forecast for Met Office

Forecast period (noon-to-noon GMT)	Forecast Global Activity level	
	Average	Max
24 JUN-25 JUN	STORM G2	STORM G3
25 JUN-26 JUN	STORM G1	STORM G3
26 JUN-27 JUN	ACTIVE	STORM G1

For more information about the forecast and activity categories see
www.geomag.bgs.ac.uk/education/activitylevels.html

Activity during last 24 hours

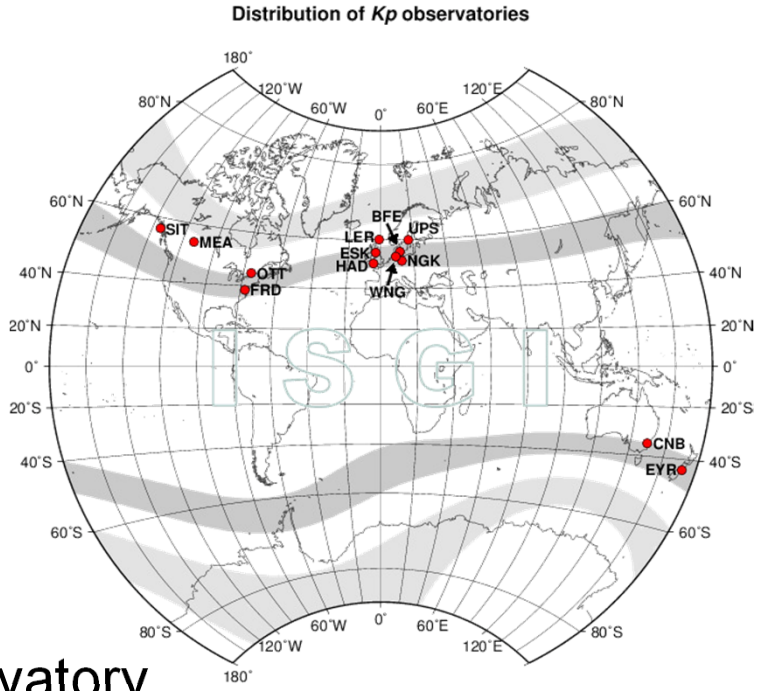
Global				Local (UK)		
Date	Average	Max	At time (UT)	Average	Max	At time (UT)
23 JUN-24 JUN	ACTIVE	STORM G1	12:00-15:00	ACTIVE	STORM G1	12:00-15:00

Additional Comments

Average geomagnetic activity has decreased back to ACTIVE over the past 24 hours. The strong southward component of the magnetic field, seen in the interplanetary magnetic field in the

Kp	BGS categories since 2014		NOAA G-scales	
	Category	Description	Category	Description
<3+	QUIET	Kp < 3+		
3+	ACTIVE	3+ < Kp < 5-		
4-				
4o				
4+				
5-	STORM G1	5- < Kp < 5+	G1	Kp = 5
5o				
5+				
6-	STORM G2	6- < Kp < 6+	G2	Kp = 6
6o				
6+				
7-	STORM G3	7- < Kp < 7+	G3	Kp = 7
7o				
7+				
8-	STORM G4	8- < Kp < 9-	G4	Kp = 8
8o				
8+				
9-				
9o	STORM G5	Kp = 9o	G5	Kp = 9

Kp and K indices



- 3 hour intervals

K:

- Identify irregular disturbances of the local geomagnetic field
- Scaled to get full range (0-9) of K at each observatory

Kp:

- Combination K values at mid-latitude observatories
- Can be estimated in real time
- Convenient method for identifying disturbances in the Geomagnetic field

Using indices to rank storms

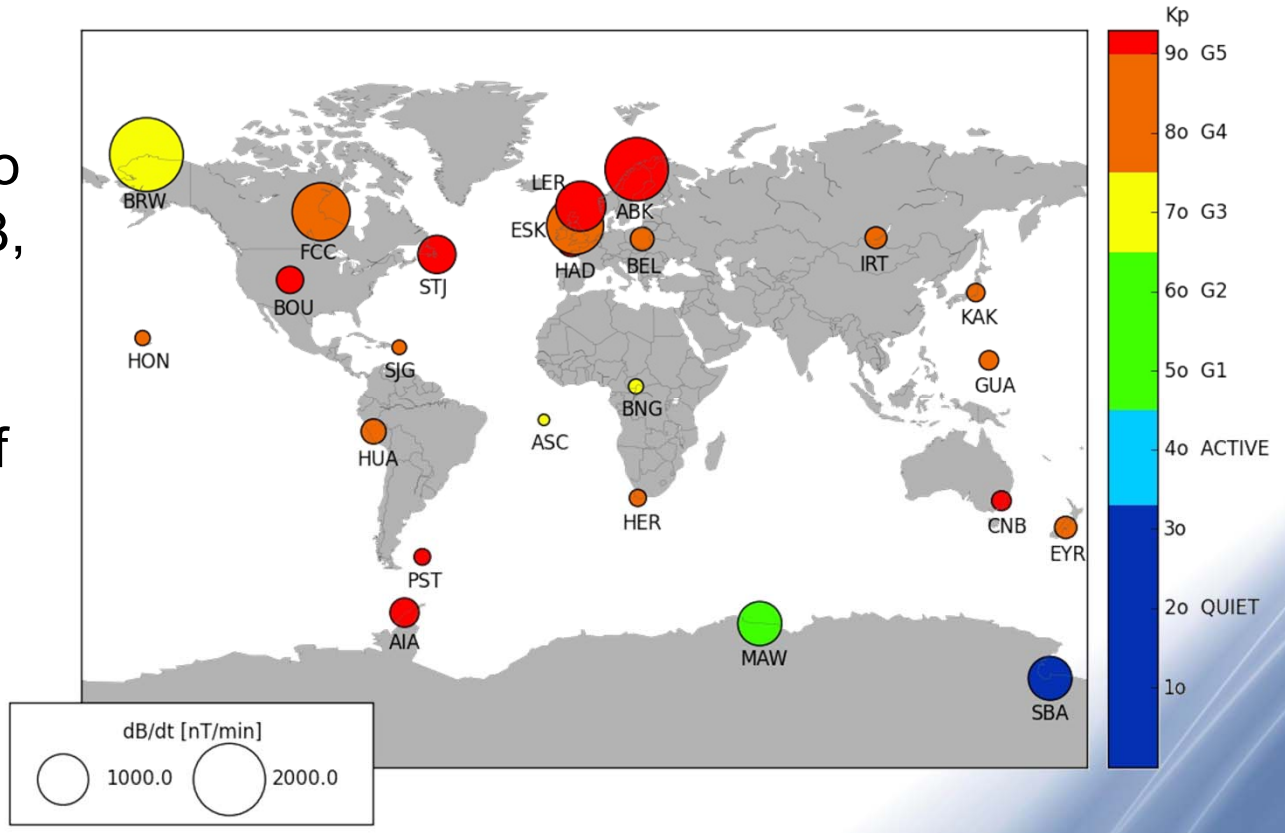
Largest storms since 1983 (when digital records began at Eskdalemuir)

Rank	Kp index	
	Peak	Date
1	9o	08-02-1986
2	9o	13/14-03-1989
3	9o	15-07-2000
4	9o	29/30-10-2003
5	9-	12-09-1986
6	9-	24/25-03-1991
7	9-	05-06-1991
8	9-	13-07-1991
9	9-	08-11-1991
10	9-	10-05-1992

Colours identify storms that occur in more than one column, those left white only appear once

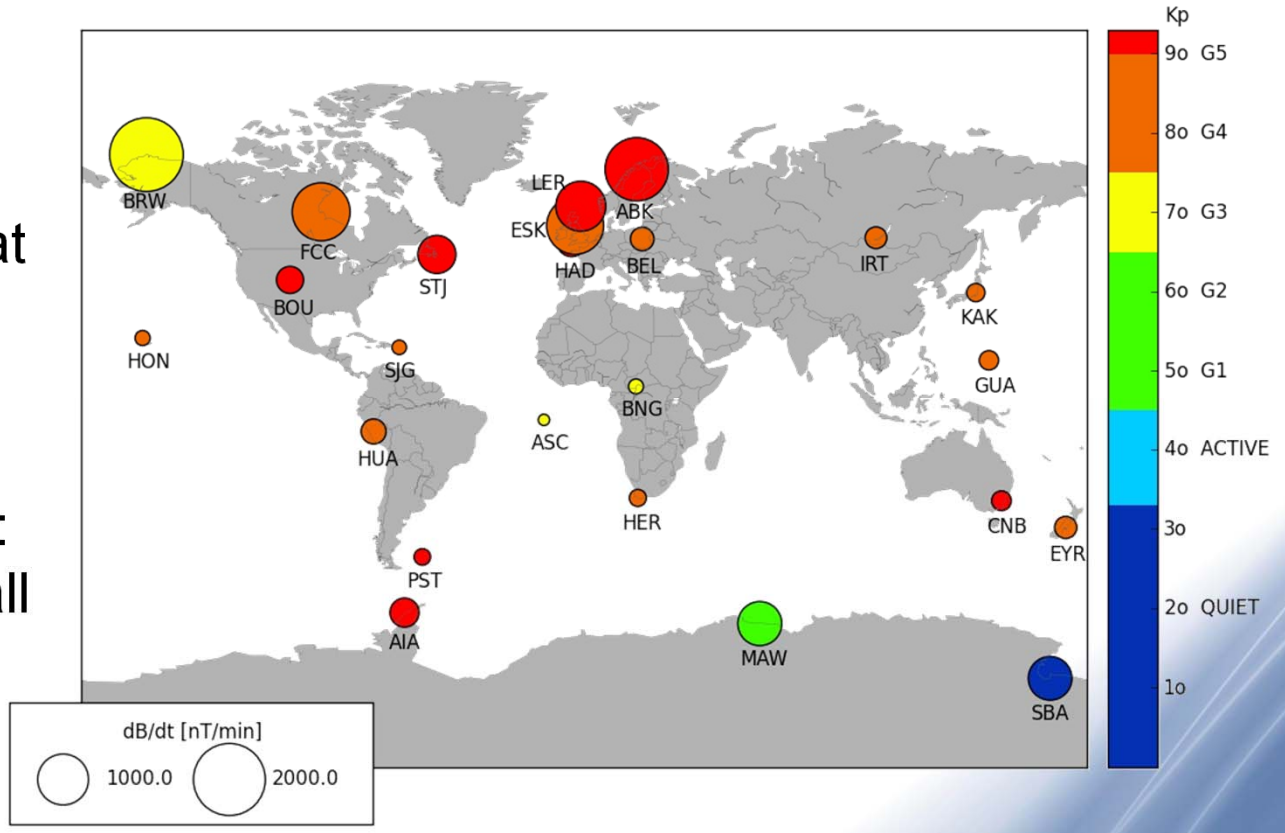
dB/dt as a proxy for GIC

- In terms of estimating risk to power grids it is generally considered most important to know the rate of change of B,
- But how useful are our current global measures of activity in identifying times of large dB/dt?
- Plot shows dH/dt
- Largest dH/dt at Kp = 9o for only 8 of 24 observatories.



dB/dt as a proxy for GIC

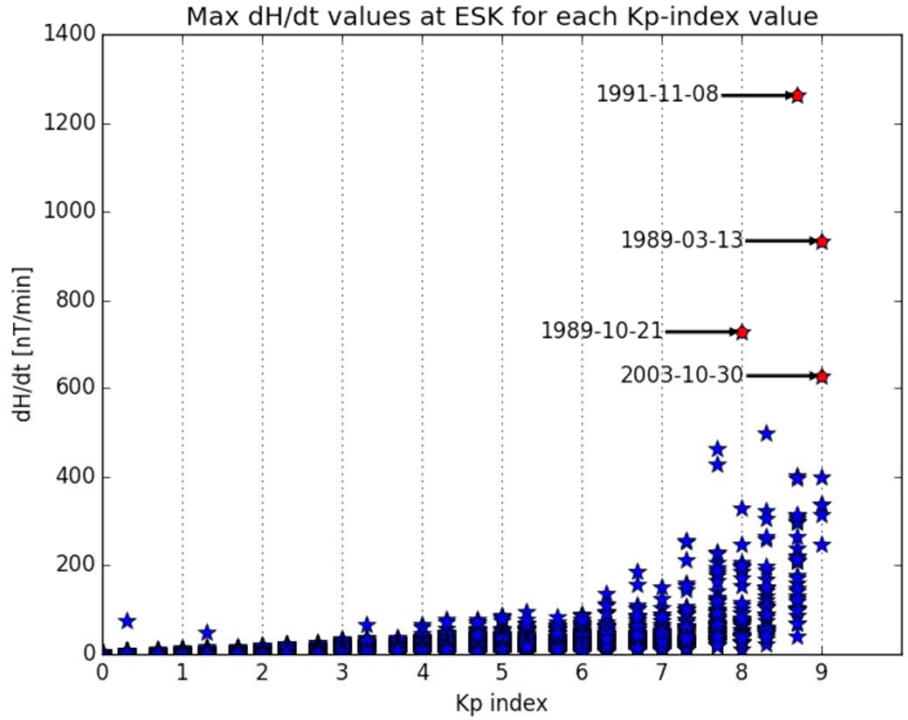
- Examples of dH/dt > **200**nT/min occurred for all values of Kp
- dH/dt > **500**nT/min reached at 8 of the 24 observatories (all > ±56° geomag latitude)
- dH/dt > **1000**nT/min was measured at 4 observatories: BRW, ABK, ESK and FCC (all > ±57° geomag latitude)



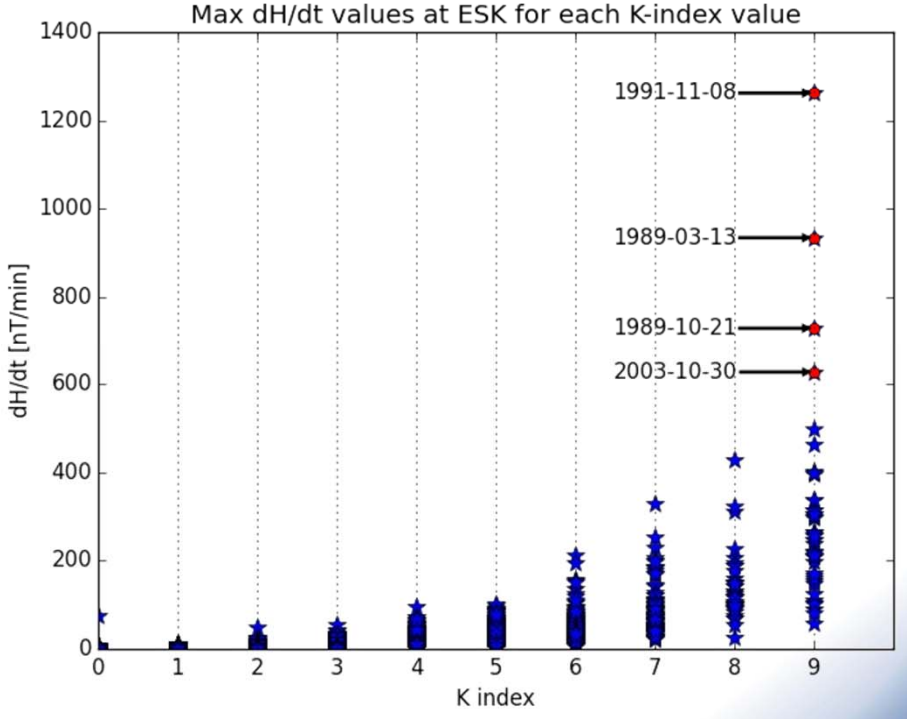
Global vs regional indices

Eskdalemuir

Kp-index



K-index

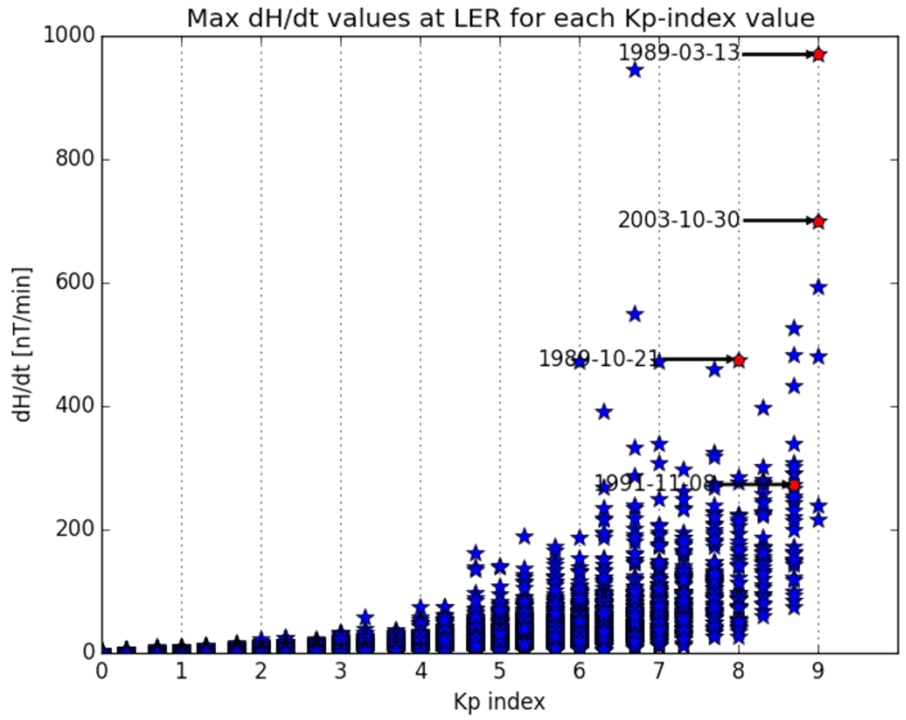


Red markers are storms reported to have had an effect on the UK power system in Erinmez et al., *J. Atmos. Sol-Terr. Phys*. 2002.

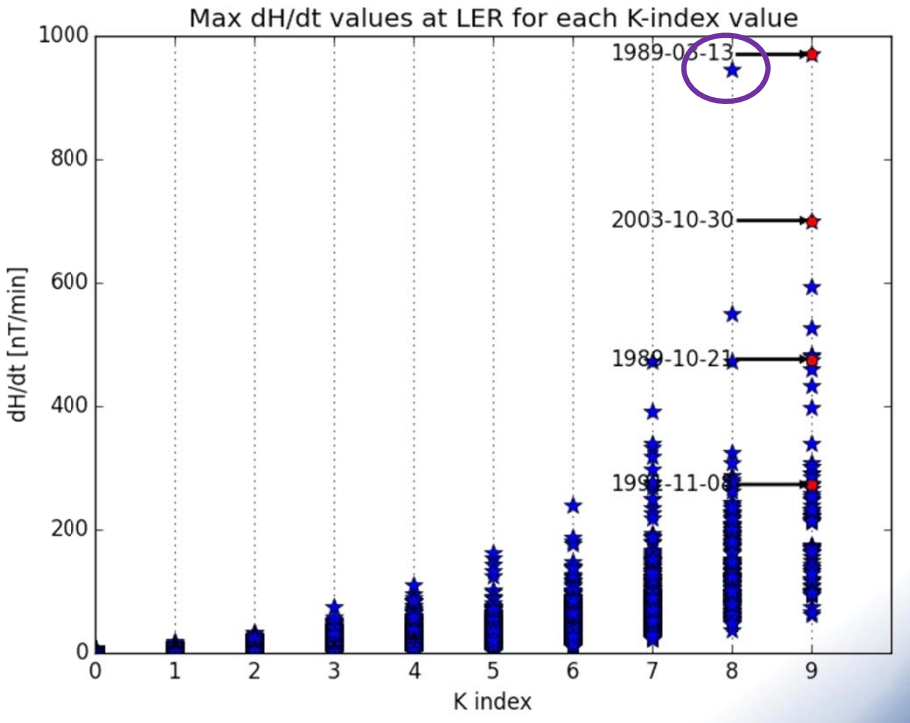
Global vs regional indices

Lerwick

Kp-index



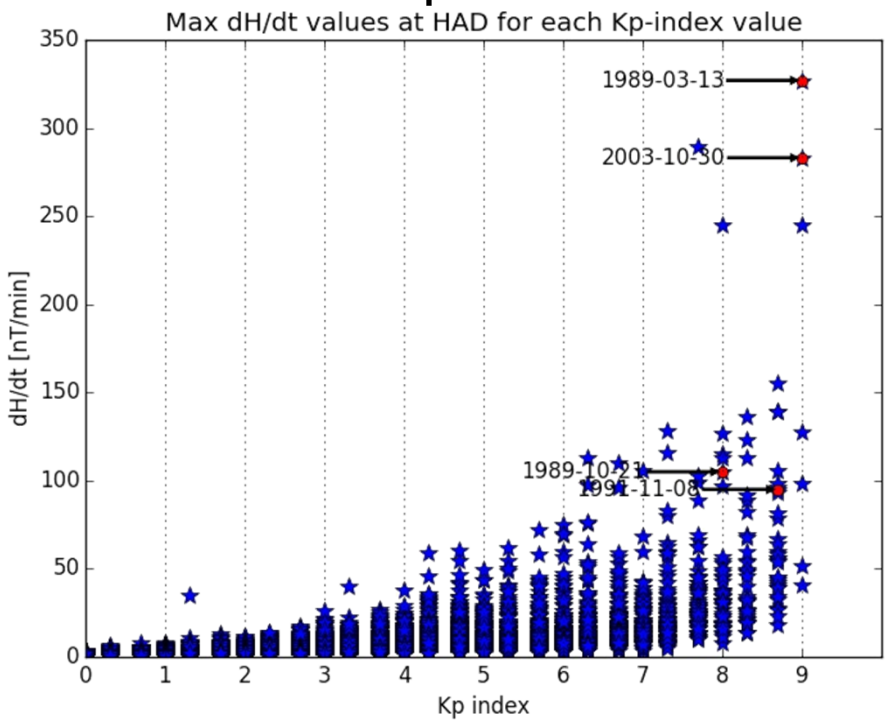
K-index



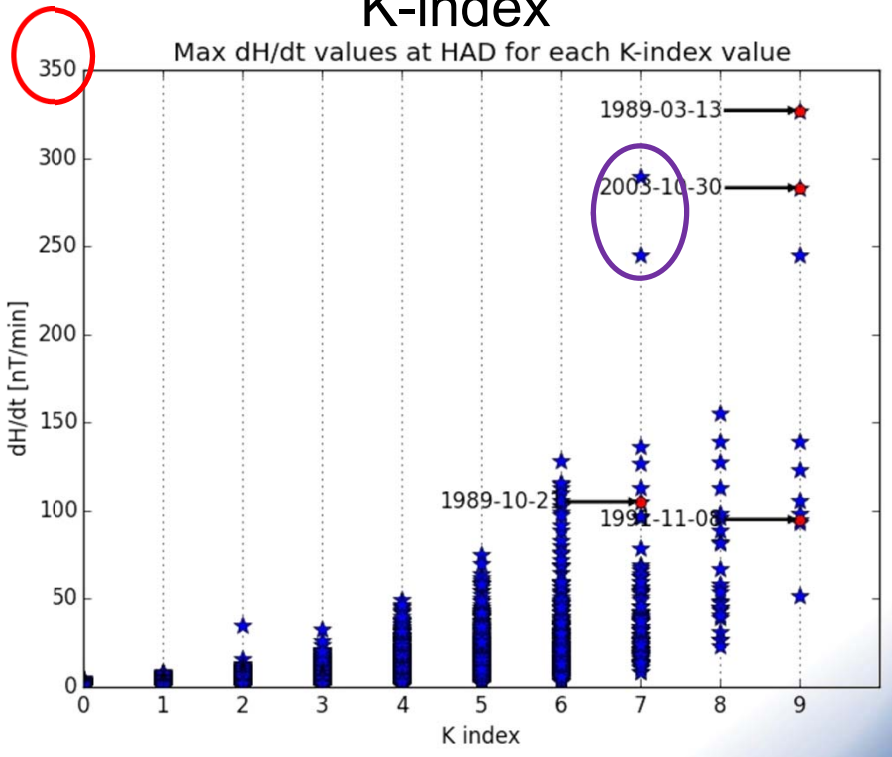
Global vs regional indices

Hartland

Kp-index



K-index

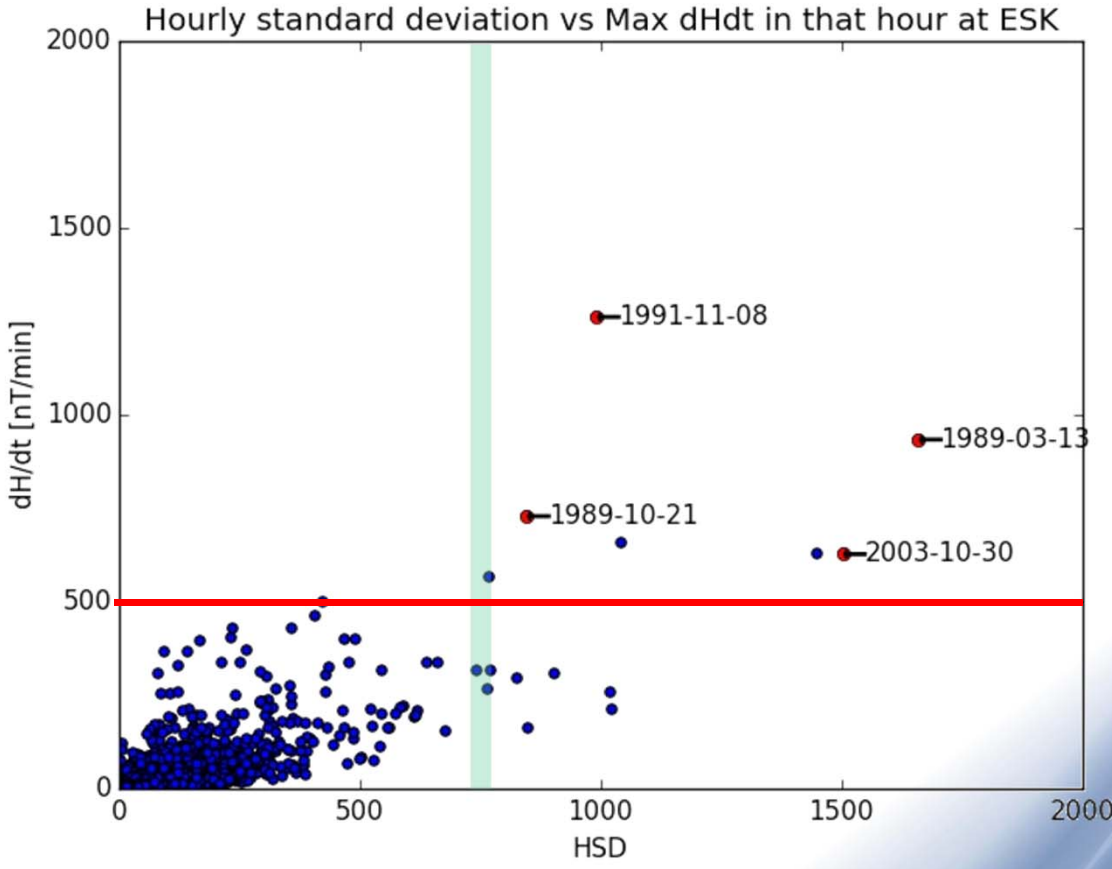


Global vs regional indices

- Global indices not as good at identifying times of large dH/dt
- Local K indices better, but still don't capture all the largest dH/dt
- There is a large range of dH/dt for each K value
  - At K=9, max dB/dt ranges from
    - 58 to 1262 nT/min at Esk
    - 63 to 970 nT/min at Ler
    - 52 to 327 nT/min at Had
- Even across a relatively small region (the UK) the max dH/dt observed varies greatly for the same Kp and K values

Hourly standard deviation

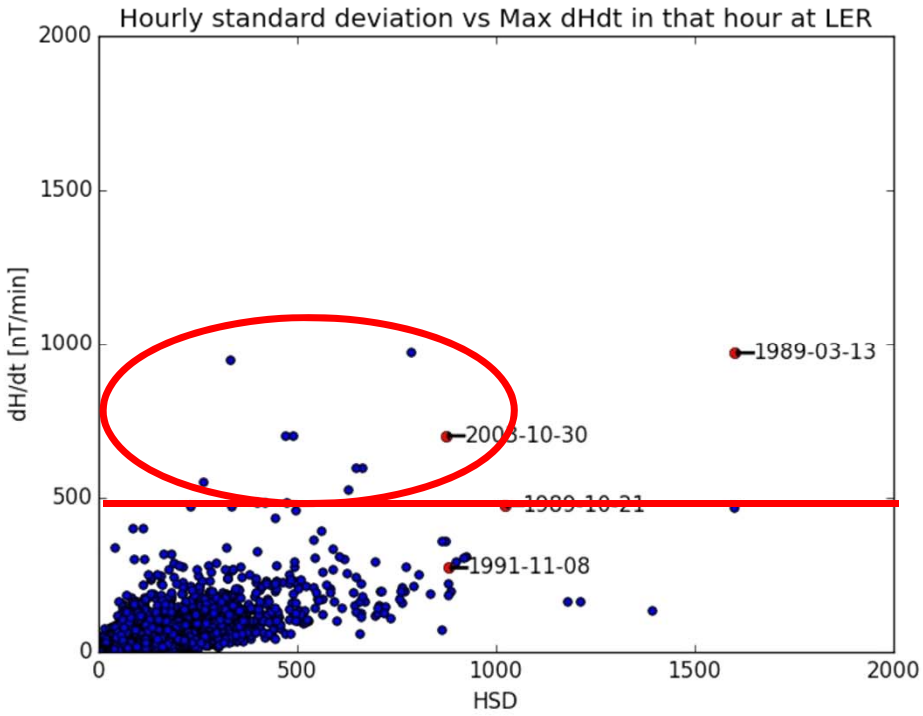
- Standard deviation within the past hour
- Robust – relatively unaffected by real-time data glitches or spikes
- Appears to do quite a good job at Esk....



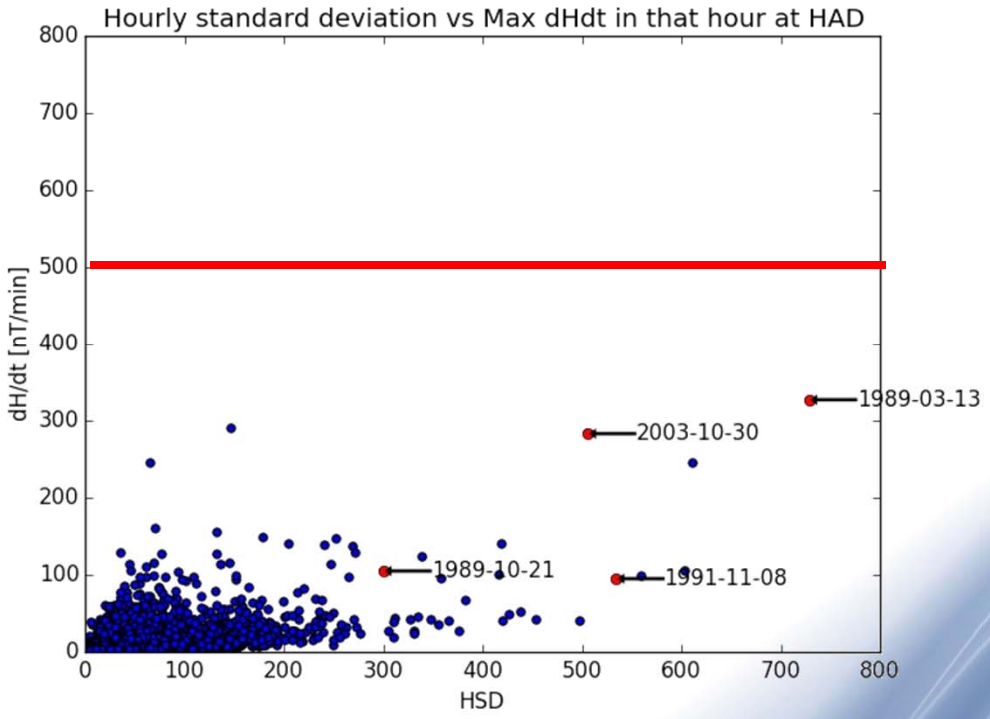
Hourly Standard Deviation

But....

Lerwick



Hartland



Still a range of dH/dt for any given HSD

Summary

- Whilst Kp provides a useful global measure of activity it does not capture local and shorter time scale information that is important for GIC
- Local measures (e.g. K and HSD) are better, but still miss some large dB/dt
- Some shorter time period measure may be better, e.g. 30-min standard deviation, or other indices such as the α_{15} index
- Or perhaps alerts should just be based on dB/dt itself
- Forecasting even global levels of activity is difficult – there is still much to do!