Correlation between SQUID and Fluxgate magnetometer data-sets for geomagnetic storms

T. K. Matladi, C. J. Fourie, T. J. Phiri, E. F. Saunderson, D.J. Gouws, C. Kwisanga

Validation of the Hermanus SQUID as a Space Weather instrument

Technical issues of the Hermanus SQUID

Space weather as a driver for geomagnetic storms

First study: geomagnetic storms

LSBB and surrounding Magnetic Observatories

Second study: geomagnetic storms

Hermanus SQUID verified against observatory data

Future study:

Identification of other frequency sources in SQUID data

The HTS SQUID at Hermanus

Located at Hermanus, ZA, - INTERMAGNET observatory

Magnetically clean environment - observatory standards

Low geomagnetic field, 10 uT horisontal and 23 uT vertical

High Temperature – cooled in liquid Nitrogen

Completely unshielded in local Earth’s field

Only X and Z axes

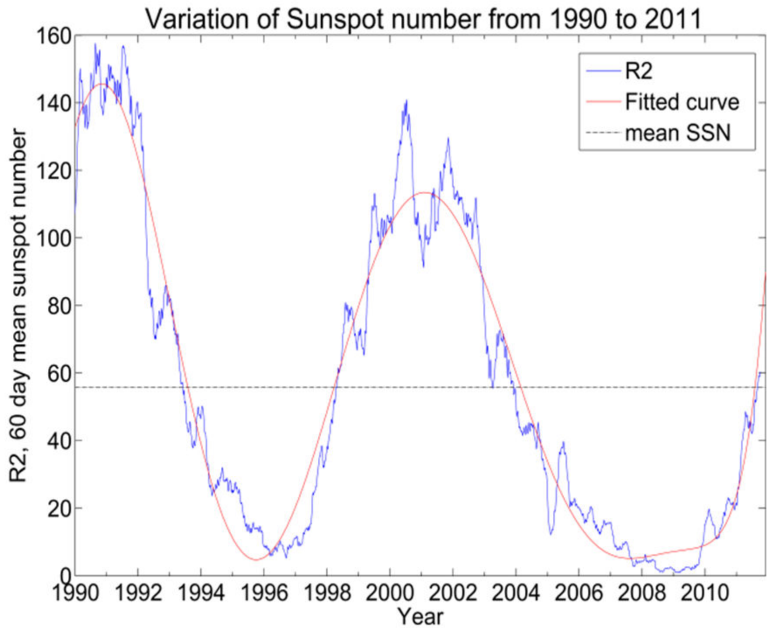
Aligned as best possible with X and Z axes of observatory fluxgate

Evaporation rate 0.8 cm/day

Refill 34 litres once per month

Space Weather:
Impact of Solar Activity on Technology

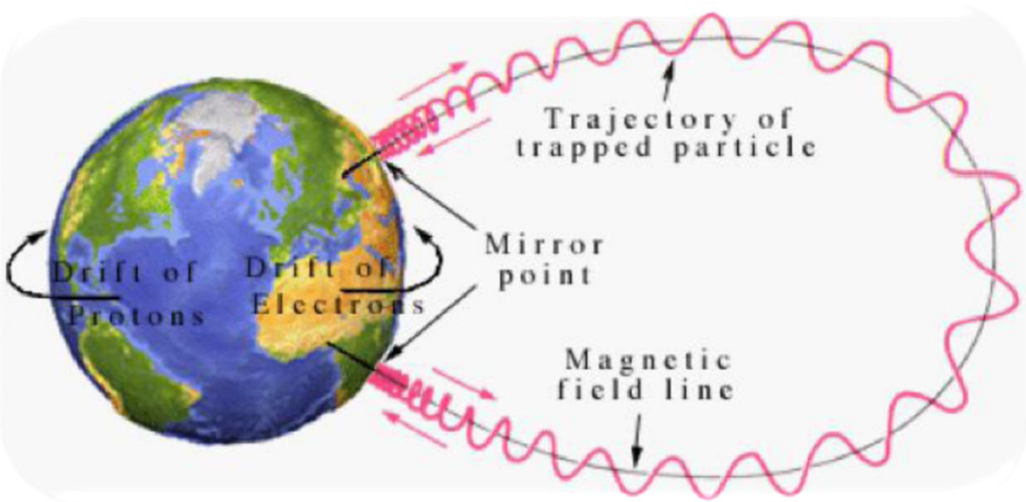
Space weather: influence of the sun and solar wind on the near-space environment in a manner that affects performance and reliability of various technological systems (GPS, HF communications, internet)



solar wind – extension of corona into space (carrying IMF) as a plasma – 400 km/s

Factors influencing Space-Earth environment

- Coronal mass ejections (CME's), Solar flares etc
- Trapped particles in field give rise to radiation (Van Allen) belts
- Spiralling, bouncing and drifting motions across field lines gives rise to ring current
- Magnetic sensing for Space weather prediction (IMF) & solar wind-magnetosphere dynamics

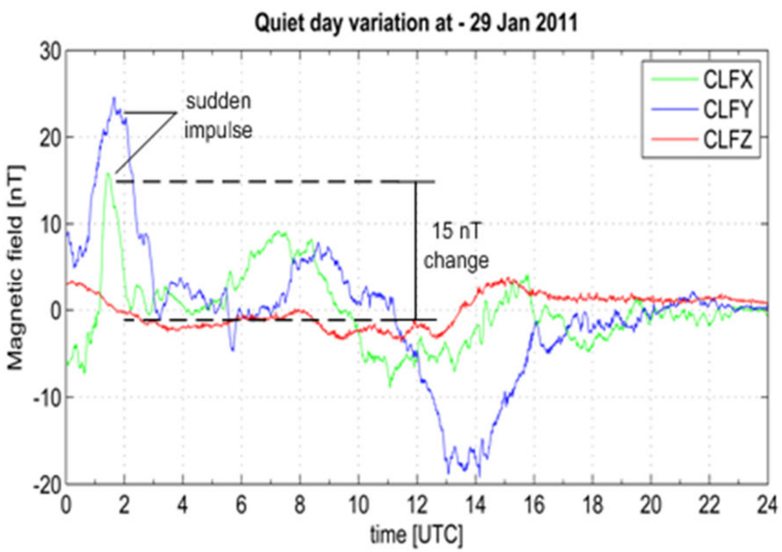


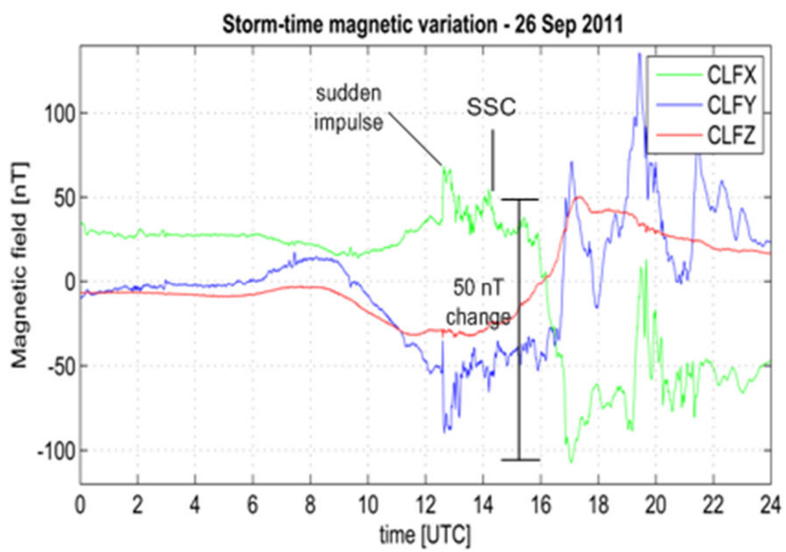
Fluxgate – vector magnetometer

- Used at most observatories
- Sampling at 1s averaged to 60s (16.7 mHz) on INTERMAGNET

Geomagnetic Storms

- Ionospheric currents give rise to S_q variation – unique to latitude
- Geomagnetic storm – strong perturbation of the geomagnetic field
- Ring current increases due to injection of plasma into magnetosphere – reconnection (southward IMF-B_Z)
- Sudden decrease in *H*-component (or *X*-component) due to increase in ring current energy in the magnetosphere





Correlation between SQUID and Fluxgate Magnetometer Data for Geomagnetic Storms (2011)

T. J. Phiri

Fluxgate data:

- Chambon la Forêt (CLF 48.0°N 2.3°E) France
- Ebro (EBR 47.1°N 0.5°E) Spain
- Fürstenfeldenbruck (FUR 48.2°N 11.3°E) Germany
- Hermanus (HER 34.4°S 19.2°E) South Africa
- Hartebeesthoek (HBK 25.9°S 27.7°E) South Africa

SQUID data:

- Low-Tc 3-axis SQUID (*xyz*)
- Laboratoire Souterrain à Bas Bruit (LSBB 43.92°N 5.48°E)

Magnetic indices

Kp index

- measure of overall variability of geomagnetic field at mid-latitudes
- 3 hour intervals
- Ranging from 0 (geomagnetically quiet) to 9 (most active)
- Useful for identification of magnetically active days Kp => 5

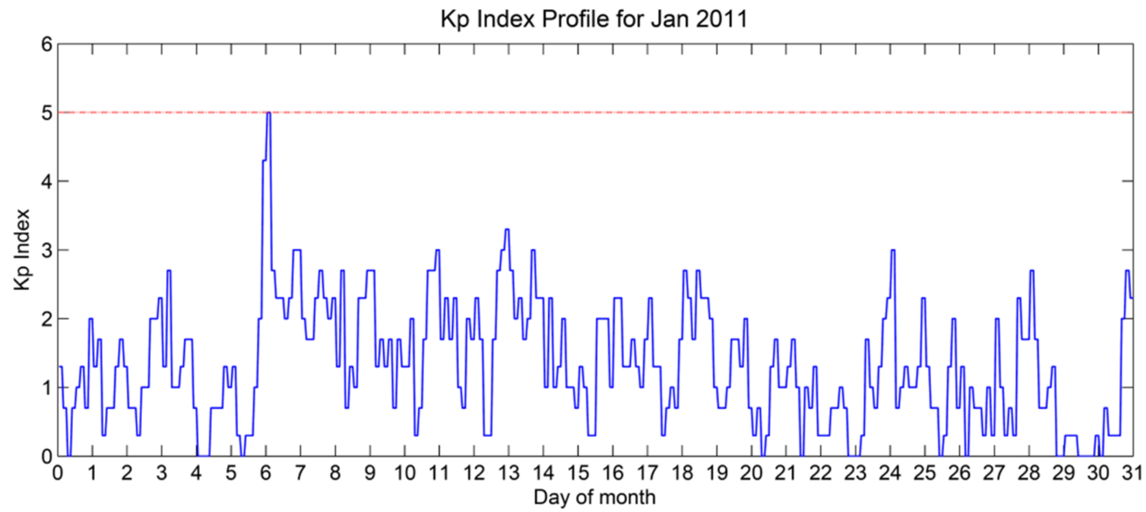
Dst (Disturbed storm time) index – classification of geomagnetic storms

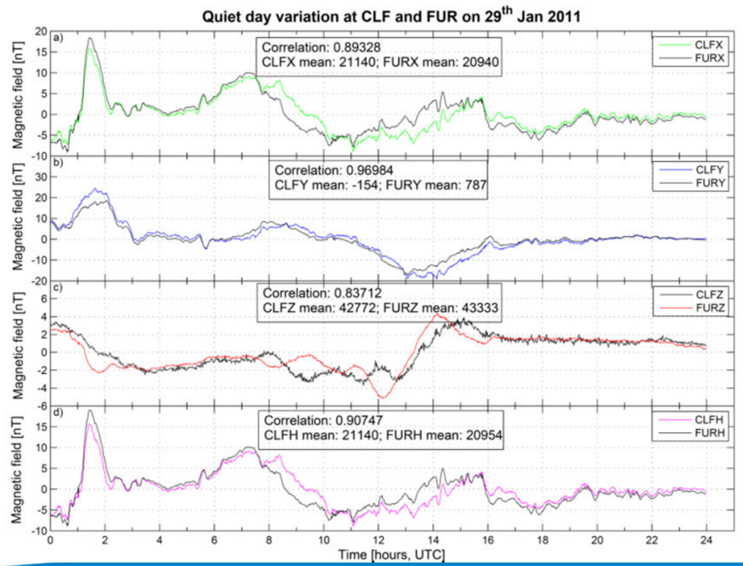
- computed using measurements of the geomagnetic surface field observed at middle and low latitude geomagnetic observatories, compared to average deviation of H-component on quiet day along equator
- Dst < -100 nT – Intense storm
- -50 nT > Dst > -100 nT – Moderate storm
- -30 nT > Dst > -50 nT – Minor storm
- Dst > -30 nT – Quiet day
- Useful to describe extent of magnetic variability

Noise Baselines

Magnetically quiet day 29 Jan 2011

Days 29 and 30 of January 2011 had Kp values less than 0.5





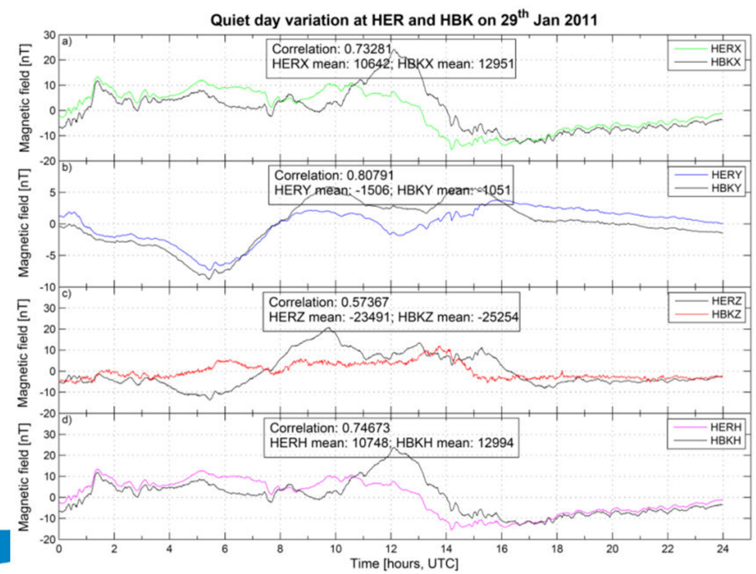
Corr

X: 0.89

Y: 0.97

Z: 0.84

H: 0.91



Corr

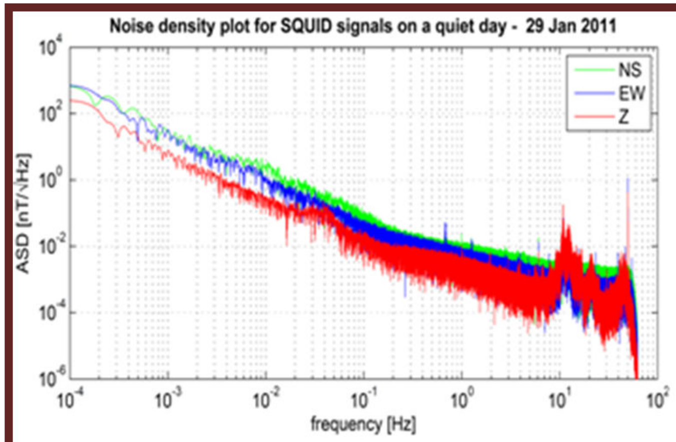
X: 0.73

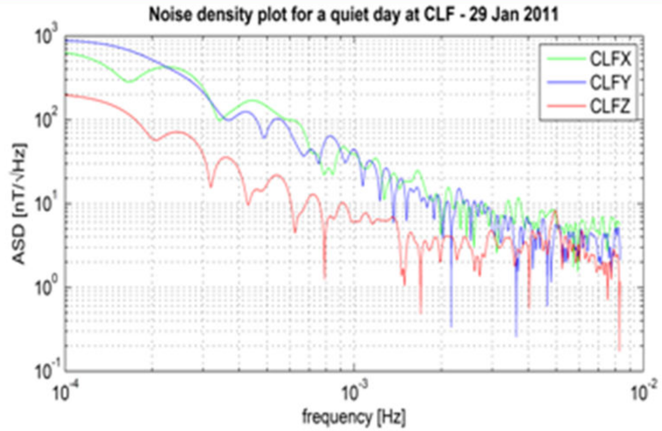
Y: 0.81

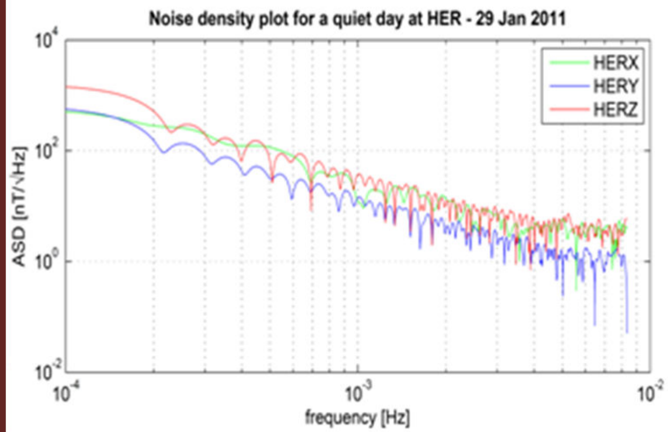
Z: 0.57

H: 0.75

- INTERMAGNET data averaged over 60 seconds, thus Nyquist frequency of fluxgate data is 8.3 mHz
- Frequencies below 1 mHz excluded due to high 1/f noise
- Fluxgate and SQUID datasets compared over frequency range 1 – 8 mHz
- SQUID noise density spectra also inspected for frequencies 10 mHz to 10 Hz
- low frequency 1/f noise driven by environmental effects, not sensor performance





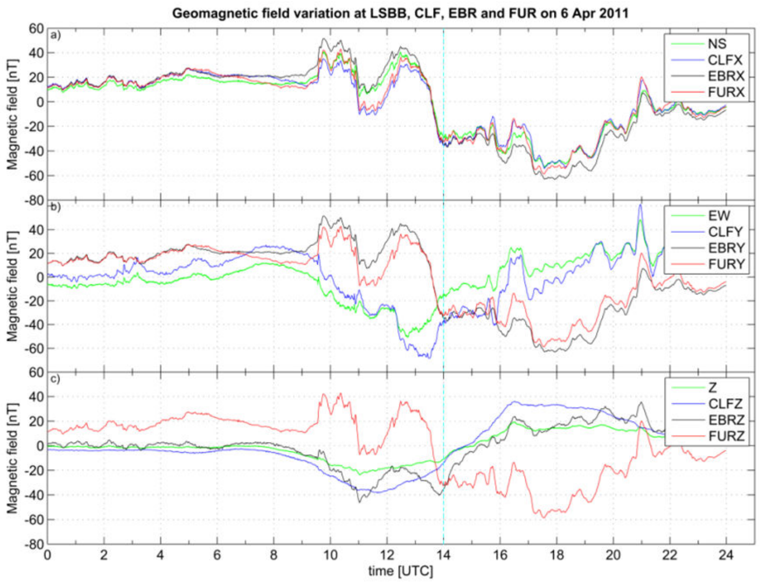


SQUID: 8.11 pT√Hz @ 1 Hz
8.00 nT√Hz @ 1 mHz

Fluxgate:
- CLF: 9.77 nT√Hz @ 1 mHz
- HER: 10.00 nT√Hz @ 1 mHz

Choice of magnetic storms 2011

Case 2 – Moderate Storm, 6 April
Kp = 5, Dst = -70 nT

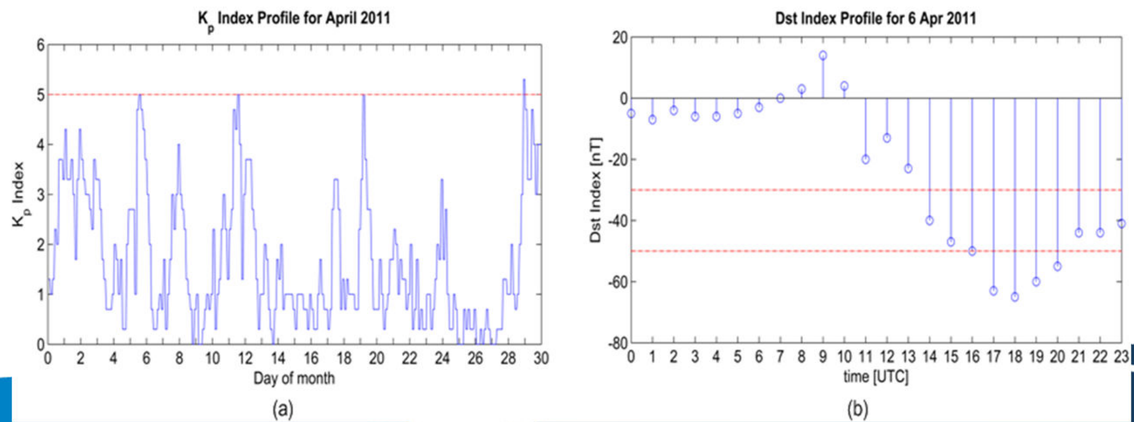


Case 1 – Moderate Storm, 1 March
Kp = 5.4, Dst = -80 nT

Case 3 – Moderate Storm, 28 May
Kp = 6.4, Dst = -95 nT

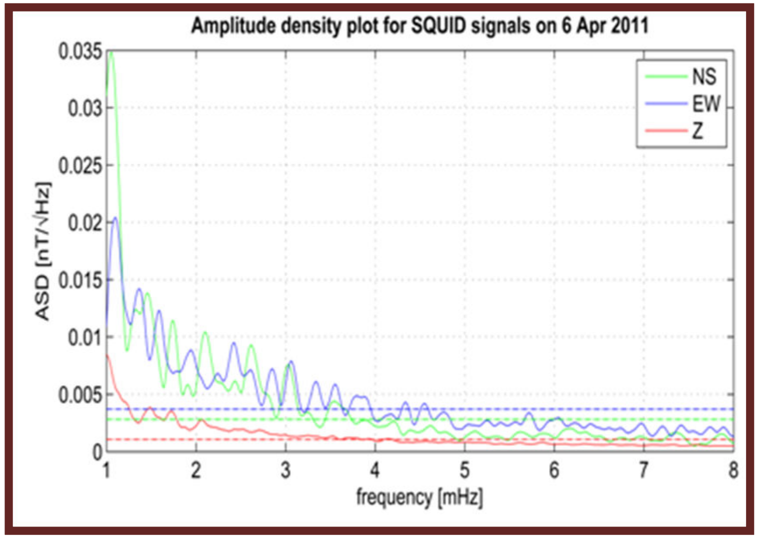
Case 4 – Intense Storm, 6 August
Kp = 7.8, Dst = -110 nT

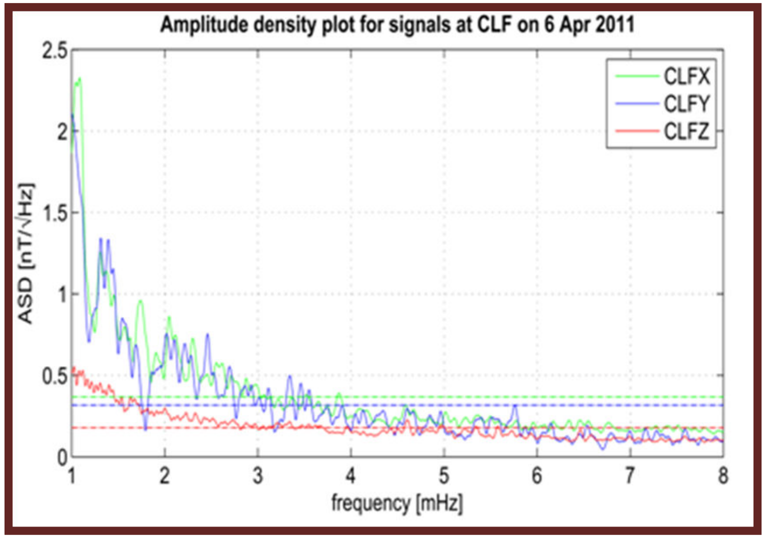
Case 5 – Intense Storm, 26 September
Kp = 6.3, Dst = -100 nT

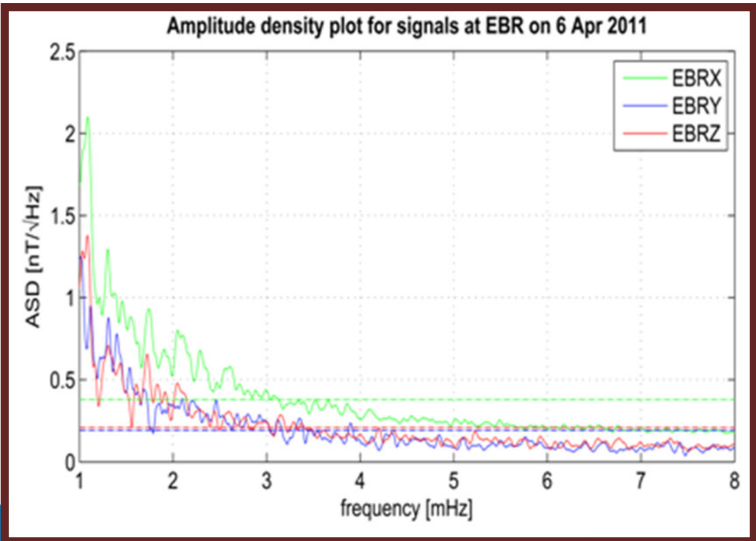


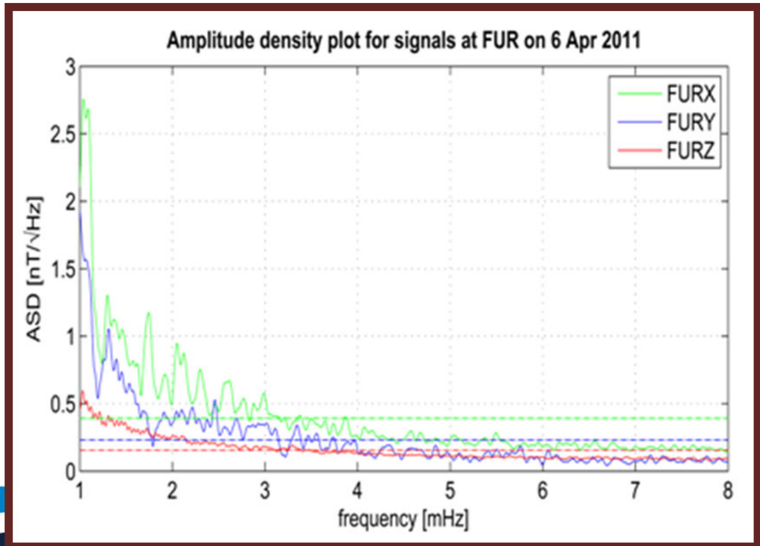
Frequency Analysis of SQUID and Fluxgate Data

Wiener-Khintchine theorem used to reduce noise









Summary of Results

Frequency Analysis of SQUID and Fluxgate Data

Case 1				Case 2				Case 3				Case 4				Case 5			
Frequency (Hz)				Frequency (Hz)				Frequency (Hz)				Frequency (Hz)				Frequency (Hz)			
X	NS	Y	EW	X	NS	Y	EW	X	NS	Y	EW	X	NS	Y	EW	X	NS	Y	EW
1.18	1.12	1.18	2.24	1.30	1.74	1.31	1.37	1.03	1.27	1.03	1.28	1.26	1.26	1.28	1.29	1.23	1.25	1.48	1.52
1.46	1.42	1.46	2.59	1.74	2.10	1.39	1.58	1.28	1.70	1.33	1.33	1.67	1.65	1.44	2.13	1.58	1.59	2.34	3.55
1.78	1.74	1.75	2.83	1.91	2.61	1.53	1.94	1.70	1.91	1.71	1.70	2.48	2.50	2.00	2.50	2.09	3.06	3.51	
2.51		1.93		2.05		2.21	2.43	1.91	2.25	1.86	1.88	2.71		2.12		2.56			
		2.22		2.60		2.46	2.46	2.31		2.63	2.59			2.50		3.06			
		2.56				2.70	3.34	3.06		3.25				2.82					
		2.72				3.34													
75%		43%		60%		86%		67%		83%		75%		50%		60%		67%	
59%				73%				75%				63%				64%			

- Frequencies recurring on *x*- and *y*-components of fluxgate data: X and Y
- SQUID components coinciding within 5% of the fluxgate values: NS and EW
- Overall, at least 59% agreement between the fluxgate and SQUID data
- Fewer frequency peaks identified on a storm day than quiet day, suggesting energy increase across selected frequency bands

Correlation between SQUID and Fluxgate data-sets for Geomagnetic storms: Hermanus (2013)

T. K. Matladi

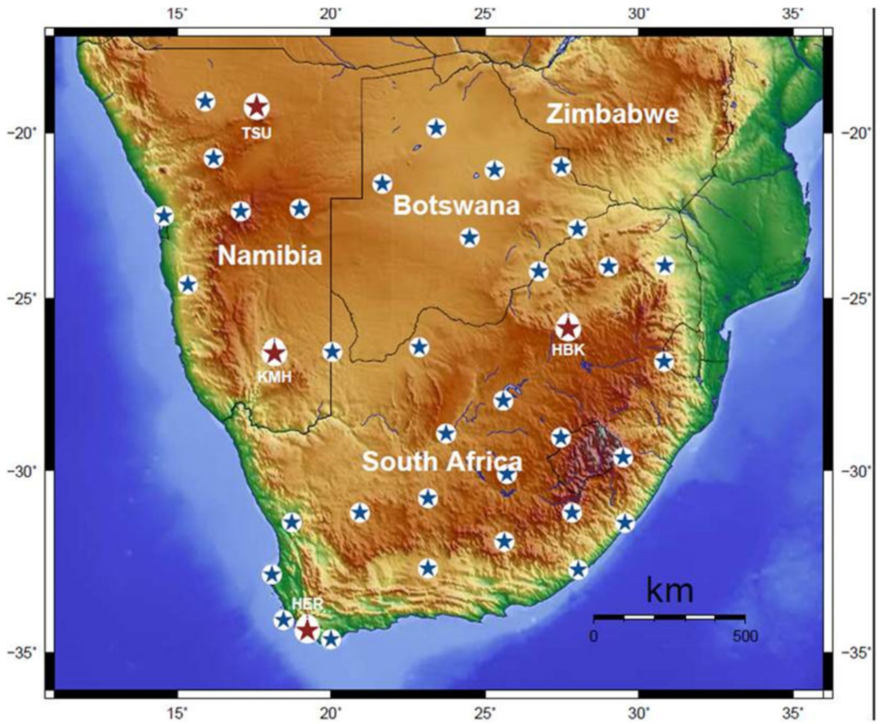
Fluxgate data:

- Hermanus (HER) – South Africa
- Hartebeesthoek (HBK) – South Africa
- Tsumeb – (TSU) – Namibia

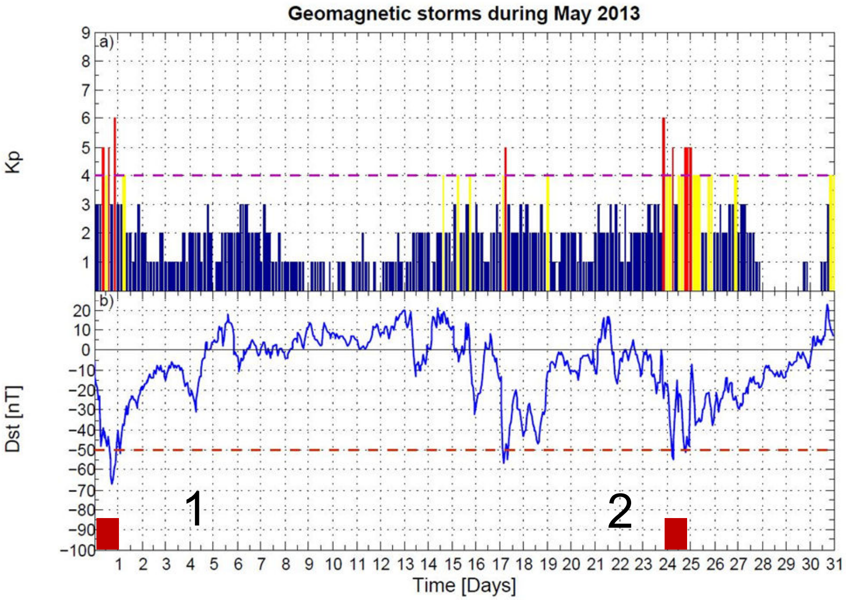
SQUID data:

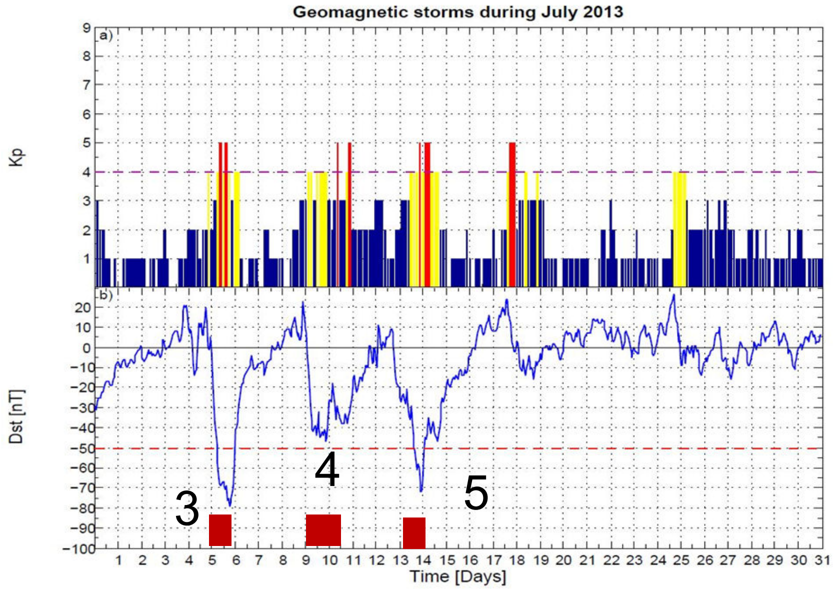
- High-Tc 2-axis SQUID (*xz*)
- Hermanus

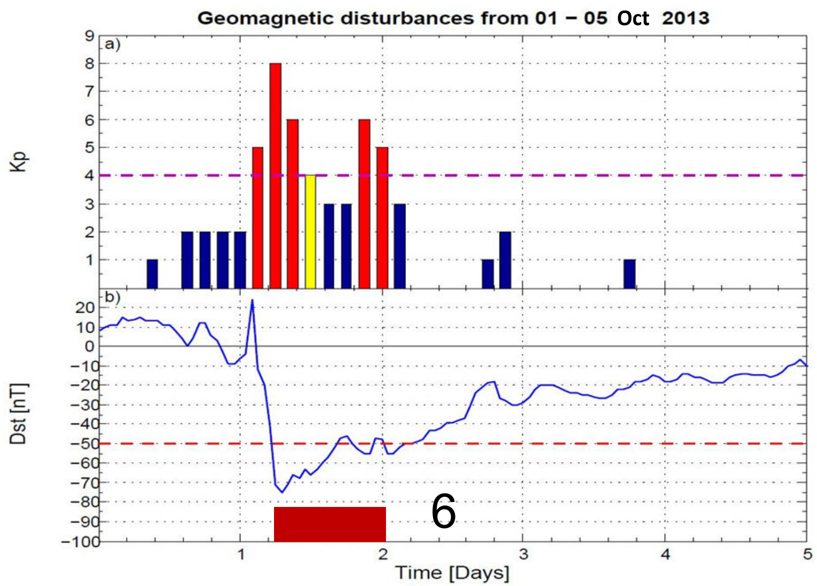
Identified storms in 2013 using Dst and Kp indices



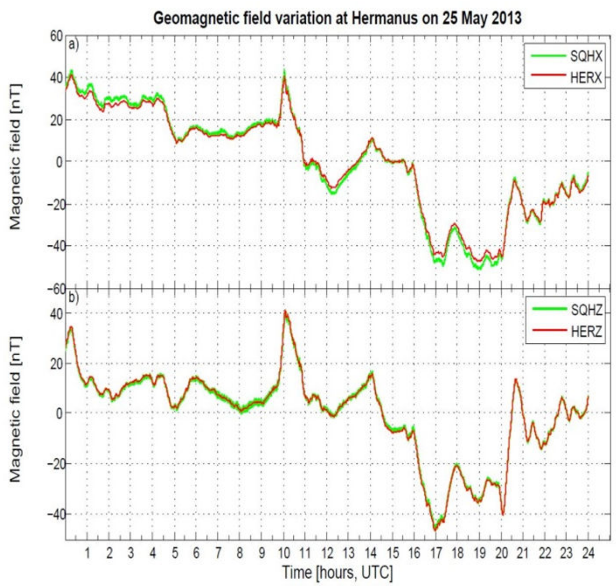
Storm Identification

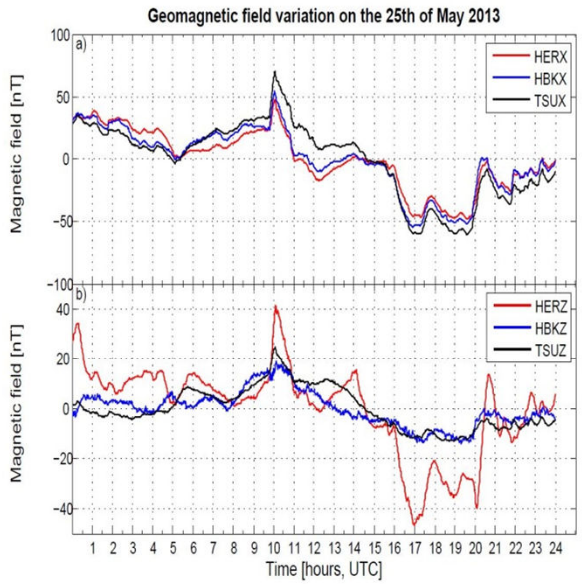


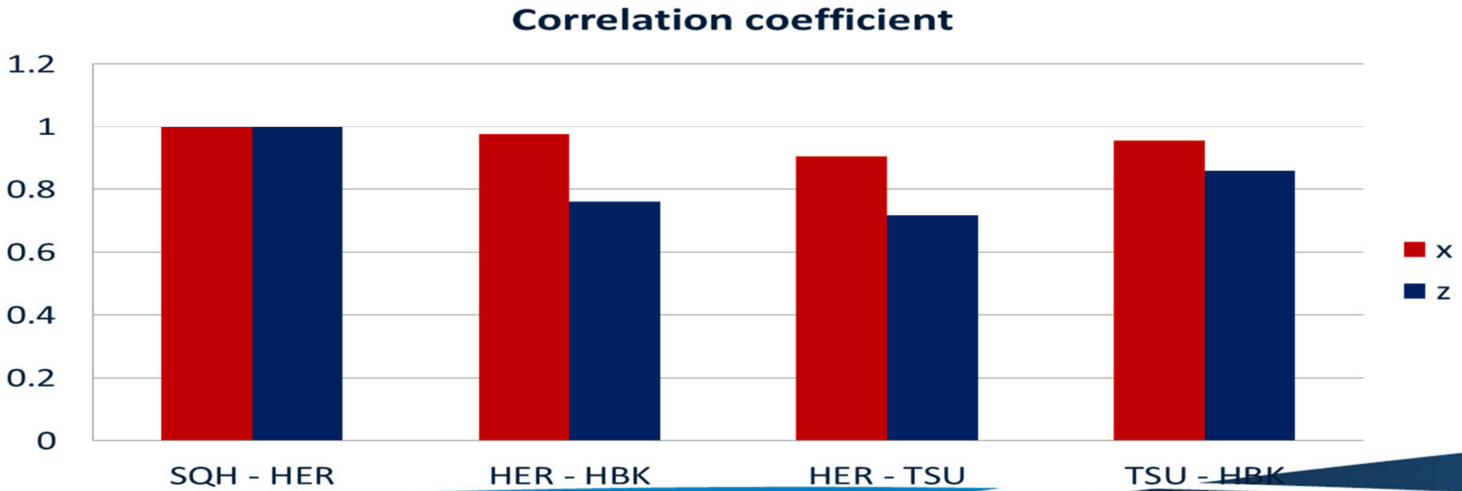




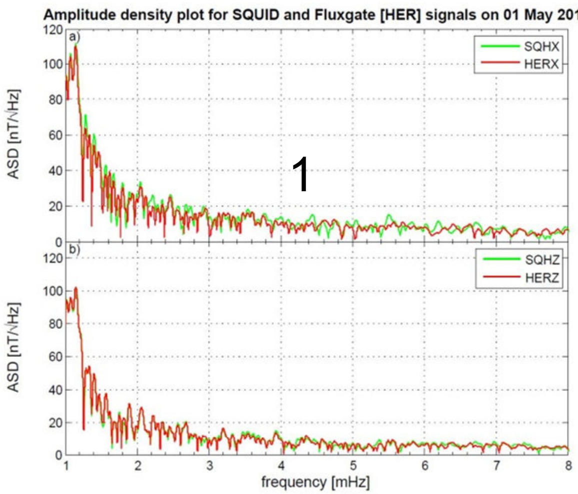
Correlation in time-domain: Storm 2

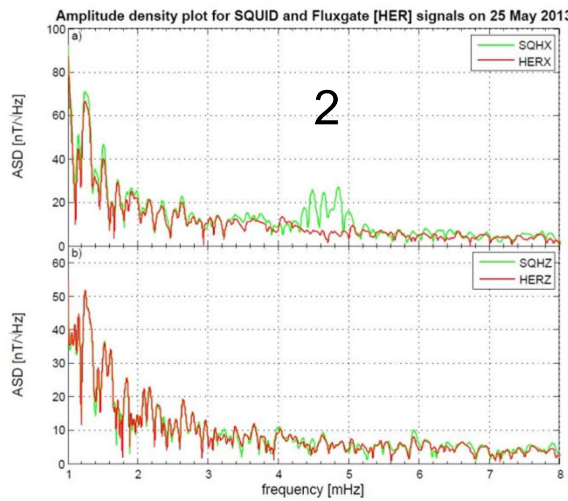


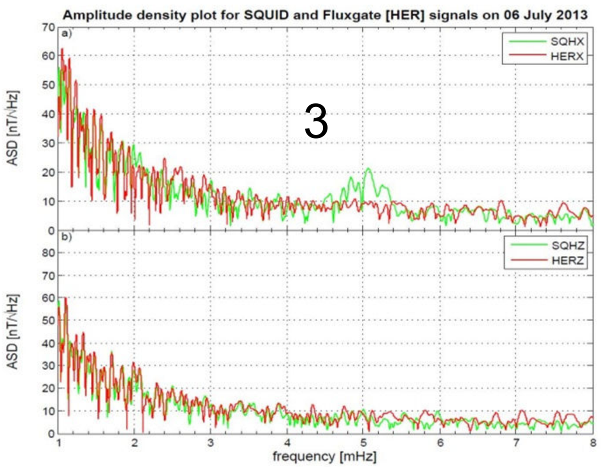


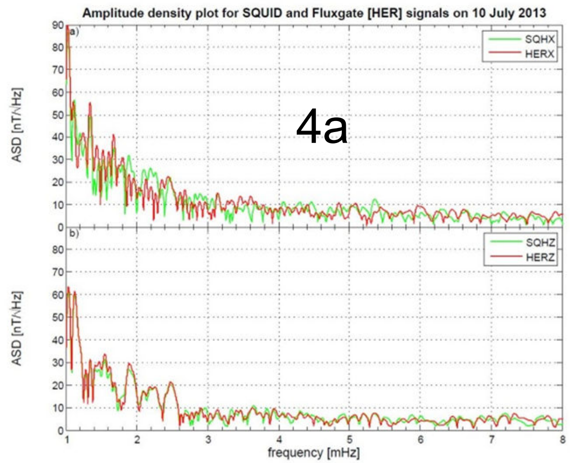


Correlation in frequency domain



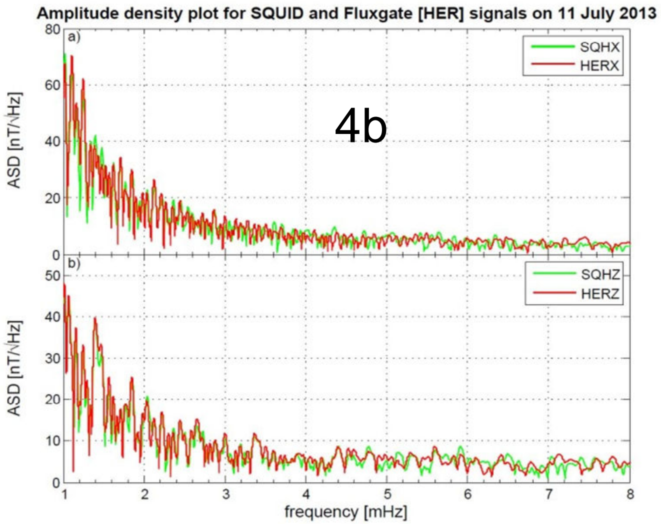


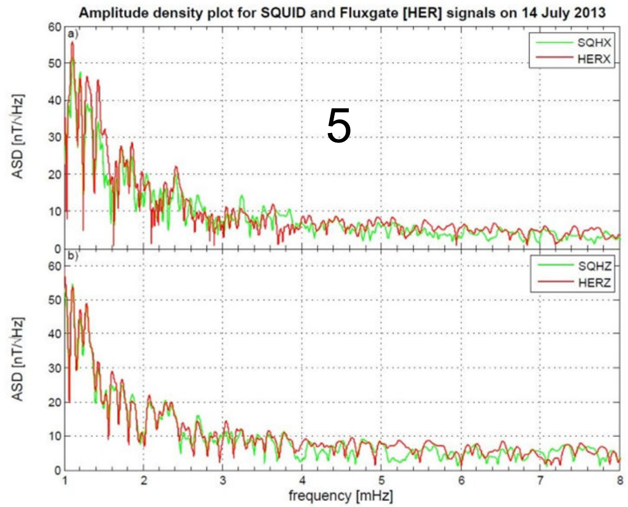


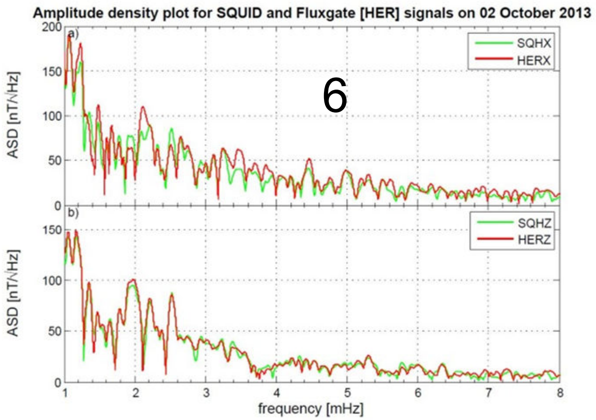


Correlation in frequency domain

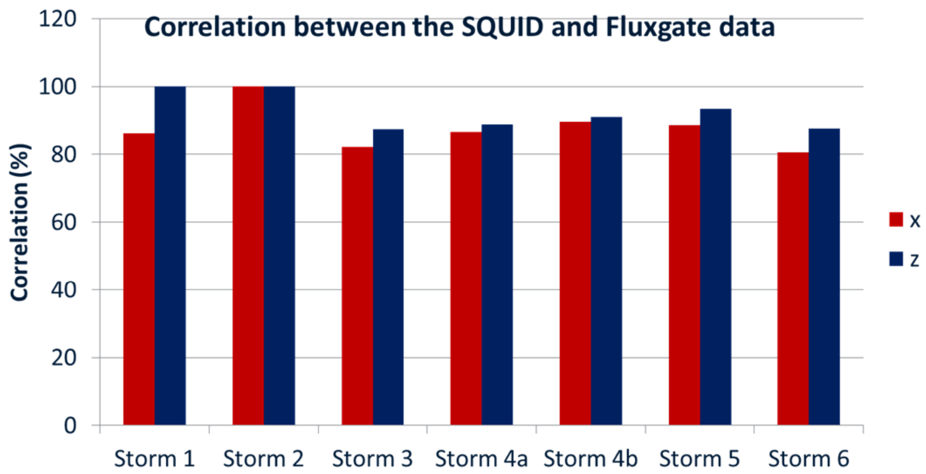
Continued…







Correlation results



Overall correlation between SQUID and Fluxgate data-sets is 90.31%

At the very least, correlation was 84.03%

Coinciding Frequency Peaks [mHz]						
Storm 1	Storm 2	Storm 3	Storm 4a	Storm 4b	Storm 5	Storm 6
1.073	1.153	1.017	1.021	1.012	1.111	1.054
1.148	**1.247**	1.064	1.125	1.106	1.205	1.473
1.289	1.510	1.106	**1.280**	1.162	**1.294**	1.788
1.336	1.609	1.158	**1.341**	**1.247**	1.430	**1.986**
1.402	1.713	**1.242**	1.416	**1.332**	1.558	–
1.473	1.774	**1.294**	1.548	**1.388**	1.605	–
1.567	**1.840**	**1.332**	1.619	1.482	1.717	–
1.619	**1.906**	**1.388**	1.670	1.567	**1.859**	–
1.670	**1.981**	1.430	**1.892**	1.619	**1.986**	–
1.755	–	1.482	–	1.713	–	–
1.802	–	1.529	–	1.760	–	–
1.896	–	1.572	–	**1.844**	–	–
1.995	–	1.661	–	**1.901**	–	–
–	–	1.708	–	–	–	–
–	–	1.760	–	–	–	–
–	–	**1.849**	–	–	–	–
–	–	**1.934**	–	–	–	–
–	–	**1.995**	–	–	–	–
2.047	2.084	2.075	2.099	2.033	2.075	2.315
2.226	2.169	2.169	2.202	2.122	2.211	2.390
2.291	2.343	2.221	2.263	2.226	2.277	**2.517**
2.353	**2.527**	2.305	2.437	2.367	2.348	**2.639**
2.418	**2.644**	2.357	**2.682**	2.447	**2.592**	**2.748**
2.461	2.762	2.447	2.823	**2.602**	**2.687**	2.992
2.564	2.865	**2.630**	2.889	**2.654**	2.809	
2.691	–	**2.682**	–	2.729	2.912	–
2.809	–	2.865	–	2.781	–	–
–	–	–	–	2.823	–	–
–	–	–	–	2.875	–	–
3.091	**3.027**	**3.002**	3.138	**3.002**	**3.049**	3.223
3.148	**3.133**	**3.096**	**3.463**	**3.190**	3.214	–
3.204	**3.383**	**3.195**	–	**3.416**	**3.369**	–
3.345	3.646	3.242	–	3.609	**3.435**	–
3.543	–	**3.420**	–	–	3.670	–
3.623	–	3.651	–	–	–	–
3.689	–	3.754	–	–	–	–
3.778	–	3.891	–	–	–	–
3.844	–	–	–	–	–	–
3.943	–	–	–	–	–	–
4.366	4.008	4.023	4.037	–	–	**4.220**
4.587	**4.135**	**4.117**	**4.300**	–	–	**4.300**
–	**4.244**	**4.164**	–	–	–	4.582
–	–	4.752	–	–	–	–
5.504	–	–	–	–	–	5.297

Simultaneous Enhancement of the Power of the 2nd Schumann Resonance observed at HERMANUS-South Africa and LSBB-France SQUID Systems

C. Kwisanga

Schumann Resonances are natural electromagnetic standing waves in the Earth – Ionosphere waveguide, created by thunderstorm activity

<u>Resonance Parameters;</u>

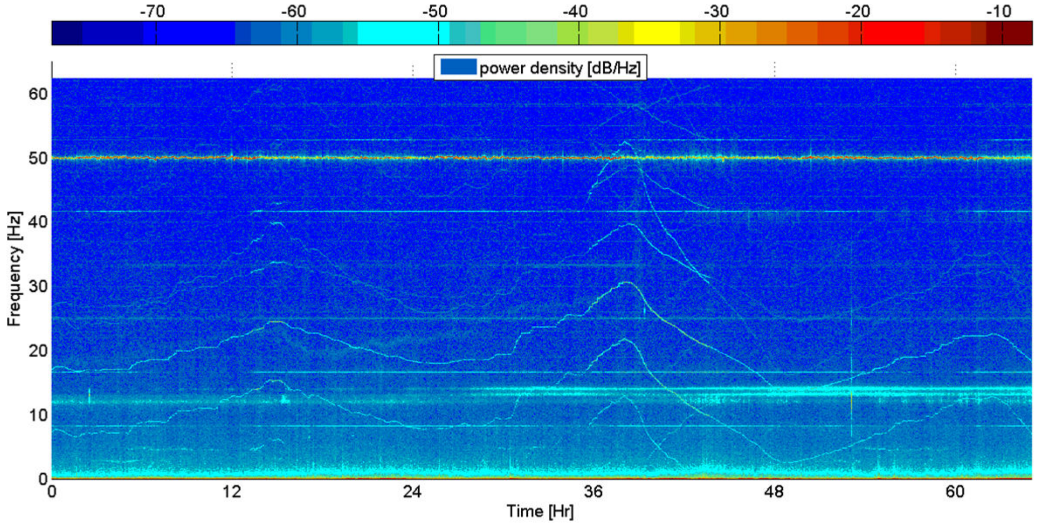
- Peak frequencies - 8, 14, 20, 26, 33, etc
- Power range (Horizontal Magnetic component) - ~1 pT^2/Hz at 8 Hz
- Bandwidth ~2Hz at 8Hz

The parameters depend strongly on

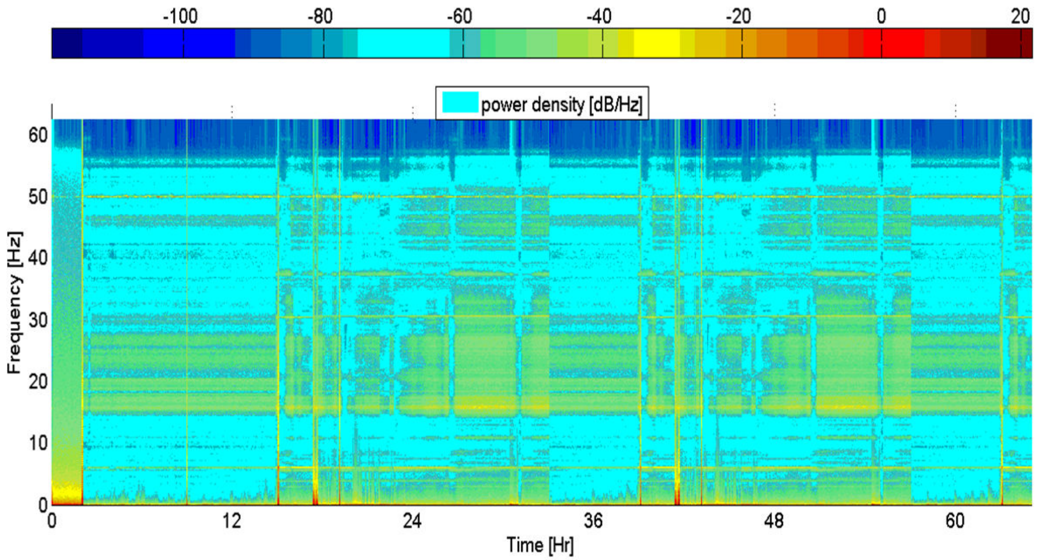
- ✓ worldwide thunderstorm activity
- ✓ lower ionosphere properties
- ✓ properties of medium of propagation

Dynamic Spectra of SQUID Horizontal Magnetic Variation

HERMANUS

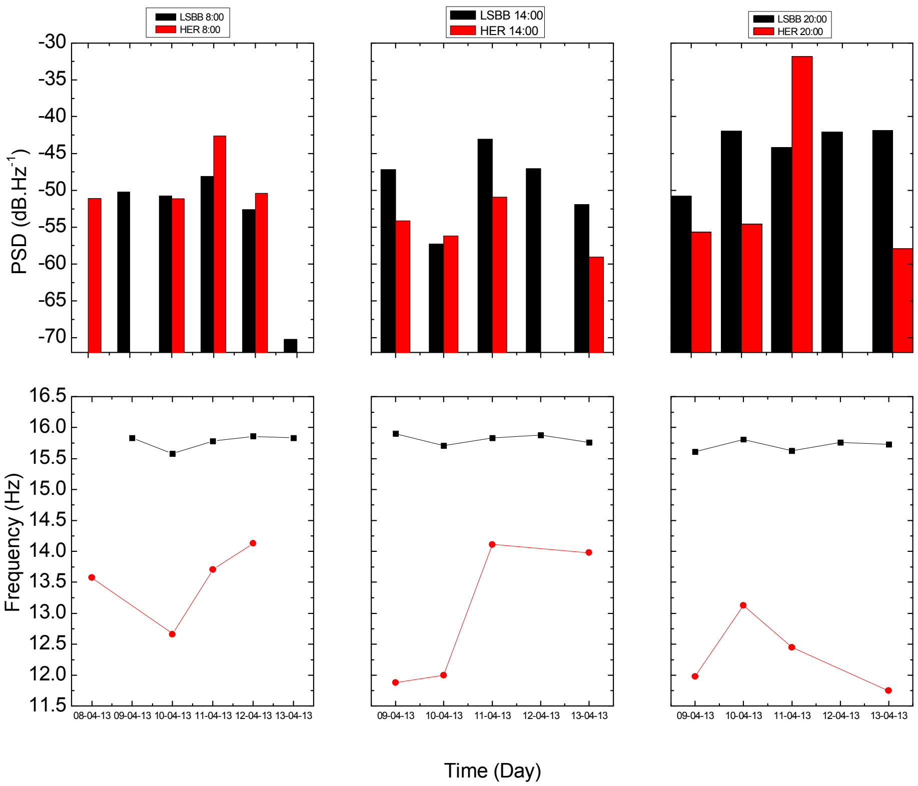


LSBB



- Measurements from 09/04/2013 at 14:00 UTC for 3 days
- Simultaneous enhancement in the power of the 15 Hz band
- Corresponds to the 2nd Schumann resonance
- 3 SR bands observed at LSBB before cutoff at 40Hz, around 15 Hz, 20 Hz and 25 Hz
- Only one band ~14 Hz observed at HERMANUS
- Higher noise level at HERMANUS: ~1pT^2/Hz at HER vs ~$10^{-2}pT^2$/Hz at LSBB

- Measured from 09/04 to 12/04/2013
- Power density and peak frequency variation of 2nd SR at 8:00, 14:00, 20:00
- Corresponds to maximum of Asian, African and American thunderstorm activity



- Maximum power observed on 11/04
- Peak frequencies variations more pronounced at Hermanus than at LSBB
- Min 12 Hz, max 14 Hz

- SQUID at LSBB (black), SQUID at HERMANUS (red)

The way forward

Confirmation of new 3-axis SQUID operation

Correlation of LSBB and HERMANUS SQUID data for geomagnetic storms 2014

Investigate other effects on SQUID:

- Lightning
- Rain
- Wind
- Tidal motions
- Pi and Pc Pulsations

Measure possible man-made magnetic disturbances at SQUID hut with higher frequency observatory grade fluxgate

Seismograph on site at HERMANUS

SOUTH AFRICAN NATIONAL SPACE AGENCY

Thank You
Dankie
Kealeboga

The presentation of this research was partially funded by the National Research Foundation, South Africa