A Statistical Study of ULF Wave events observed by the CHAMP satellite

C. Papadimitriou[1,2], G. Balasis[1], S. A. Giamini[1,3], M. Georgiou[1,2], I. A. Daglis[2,1]

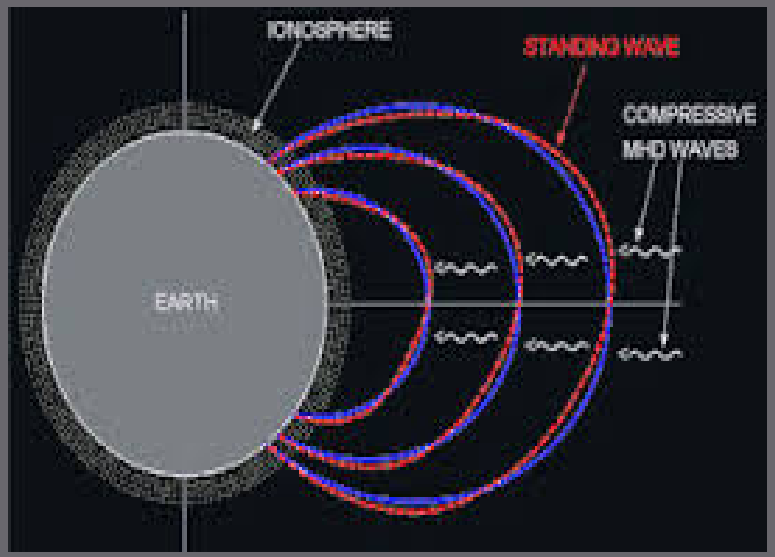
1: National Observatory of Athens – Institute of Astronomy, Astrophysics, Space Applications & Remote Sensing
2: University of Athens – Department of Astrophysics, Astronomy & Mechanics
3: National Centre for Scientific Research DEMOKRITOS - Institute for Advanced Materials, Physicochemical Processes, Nanotechnology & Microsystems

SEVENTH FRAMEWORK PROGRAMME

11th Hel.A.S Conference
Athens, 8-12 September 2013

IAASARS

ULF Waves



Pulsation classes

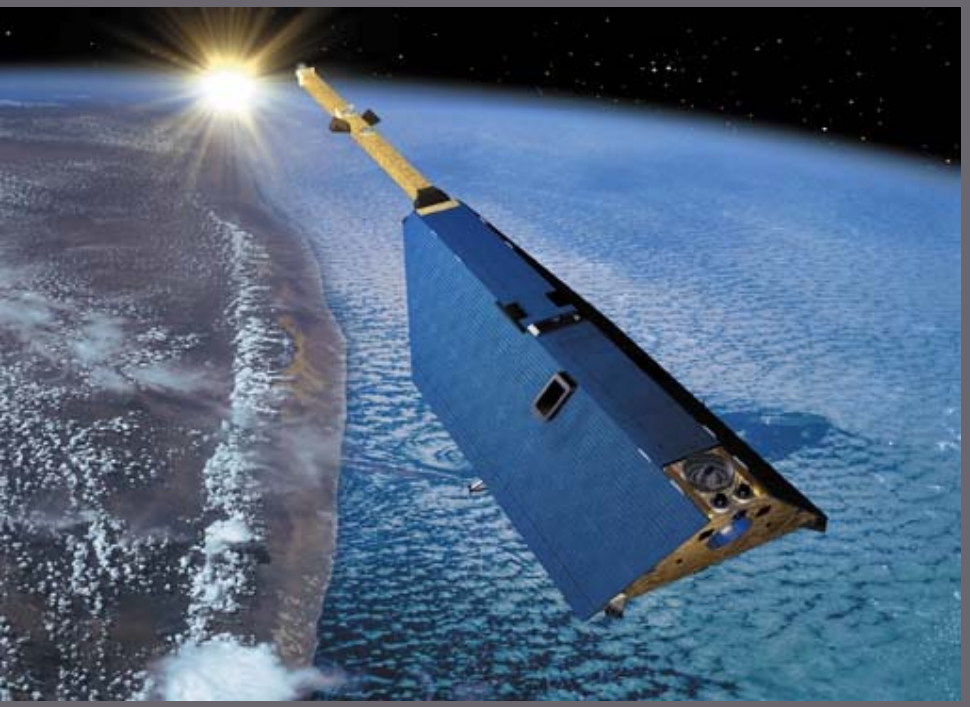
	Continuous pulsations					Irregular pulsations	
	Pc 1	Pc 2	Pc 3	Pc 4	Pc 5	Pi 1	Pi 2
T [s]	0.2-5	5-10	10-45	45-150	150-600	1-40	40-150
f	0.2-5 Hz	0.1-0.2 Hz	22-100 mHz	7-22 mHz	2-7 mHz	0.025-1 Hz	2-25 mHz

Compressional Pc 3daysideupstreamrelate to wave-particle interaction in the foreshock and shock

Toroidal Pc 3 or multi-harmonicsdaysideupstreamfield line resonance harmonics in Pc 3 / Pc 4 range, compressional Pc3 as a driver (coupling with the fundamental toroidal mode)

http://magbase.rssi.ru/REFMAN/SPPHTEXT/ulf.html

CHAMP (**CHA**llenging **M**inisatellite **P**ayload)



Launch: July 15, 2000

Design Lifetime: 5 years

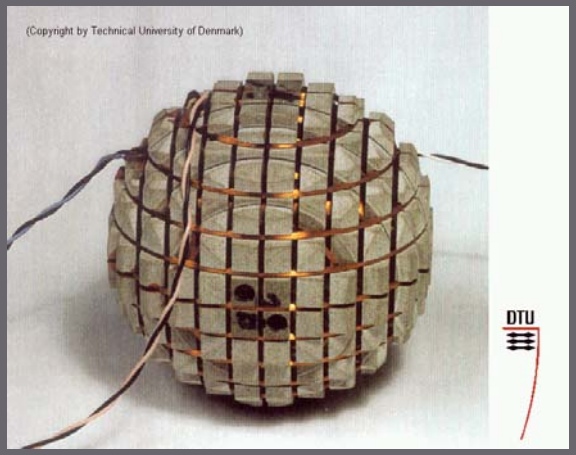
End of Mission: September 19 2010

(ten years, two month, four days)
(58277 orbits)

Orbit Characteristics:

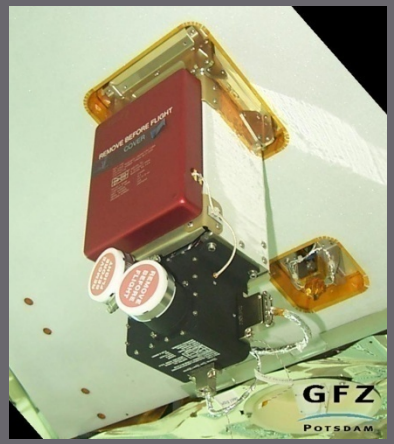
- Low Earth Orbit (initial altitude of 454 km)
- Almost circular
- Near polar (87° inclination)
- Approx. 45’ per Orbit

Fluxgate Magnetometer



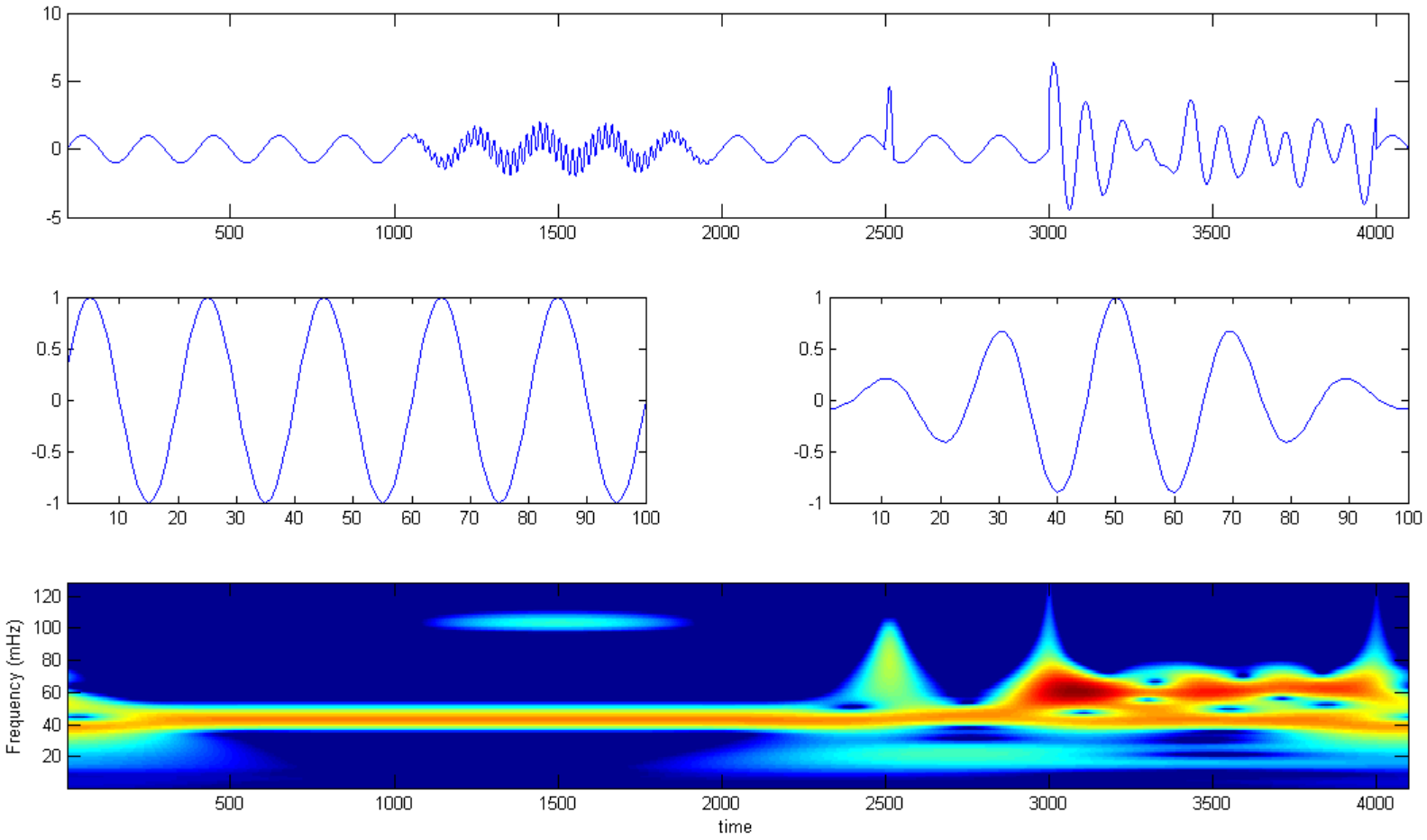
Range	±65 000 nT
Resolution	10 pT
Deviation from linearity	±100 pT
Noise level	< 100 pT (rms)
Sample rate	50 Hz (nominal), 10 Hz, **1 Hz**

Digital Ion Drift Meter



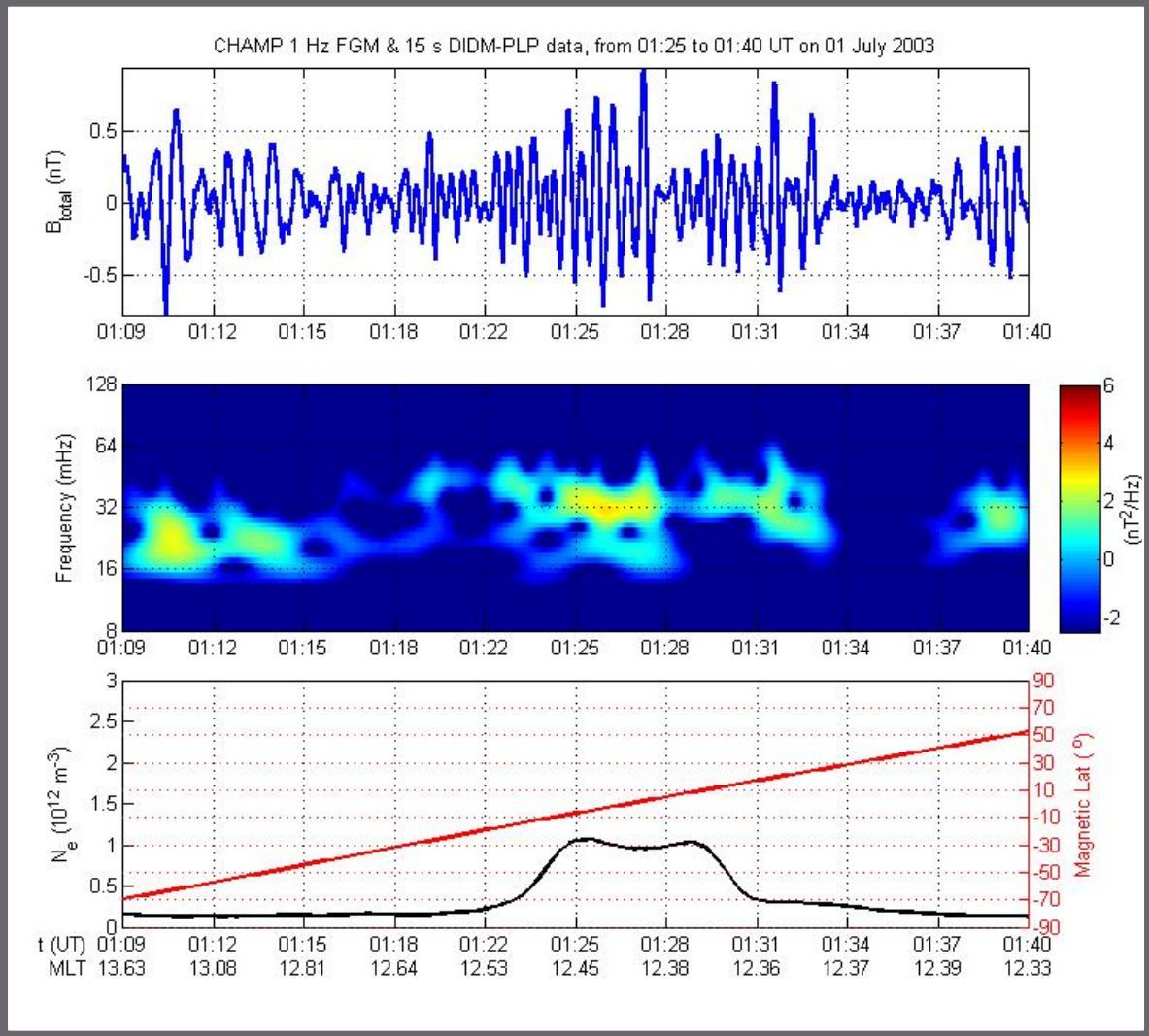
Range of ion density	10^8 - 10^{12} ions/m^3
Range of ion temperature	200 - 55 000 K
Range of drift velocity	0 - 6 km/s
Resolution of ion velocity	< 1° direction, < 130 m/s speed
Sample rates	
DM mode	0, 1, 2, 4, 8, 16 HZ
RPA mode	0, 8, 16 Hz
PLP mode	0, **1/15 Hz**

Wavelets


10
5
0
-5
500
1000
1500
2000
2500
3000
3500
4000
1
0.5
0
-0.5
-1
10
20
30
40
50
60
70
80
90
100
Frequency (mHz)
120
100
80
60
40
20
time

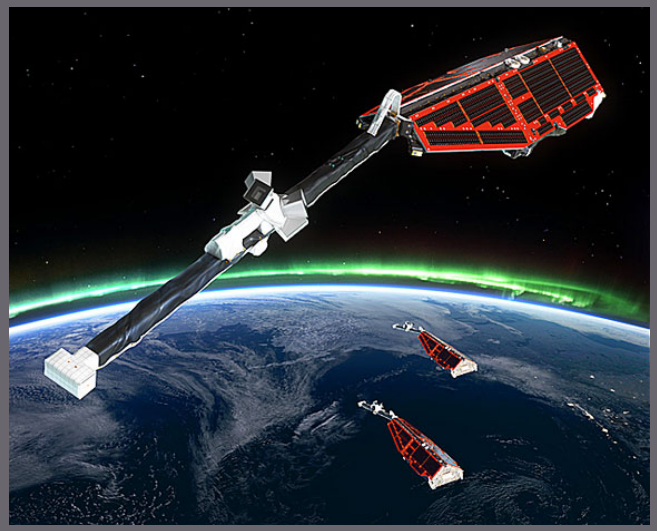
The Time-Frequency Analysis Tool

- Visualization and Study of Wave phenomena
- Data Input in a Track by Track basis
- 3 Panels
  - Filtered (external) Field
  - Wavelet Power Spectrum in the selected Pc range
  - Ion Density Data
  - Positional Information (geographic, magnetic or other coordinate systems)

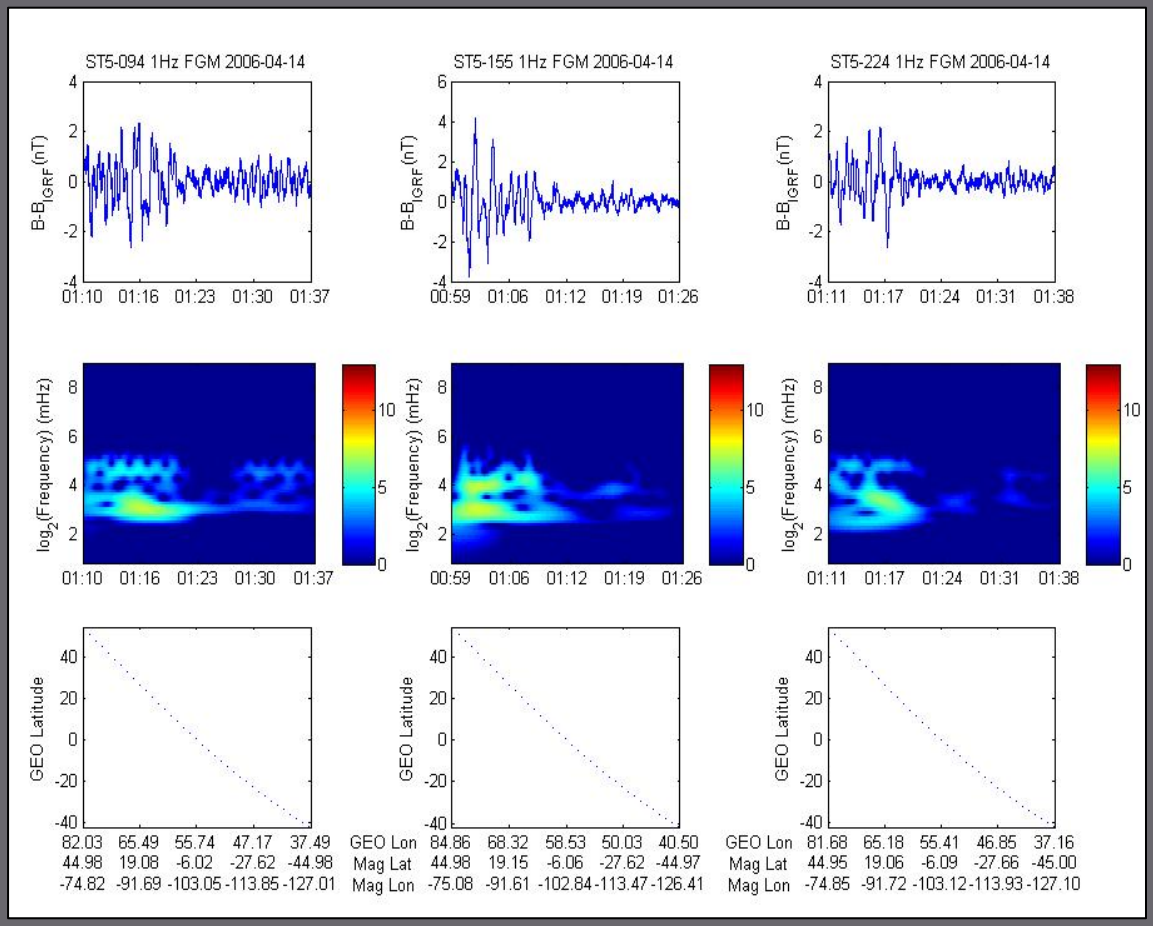


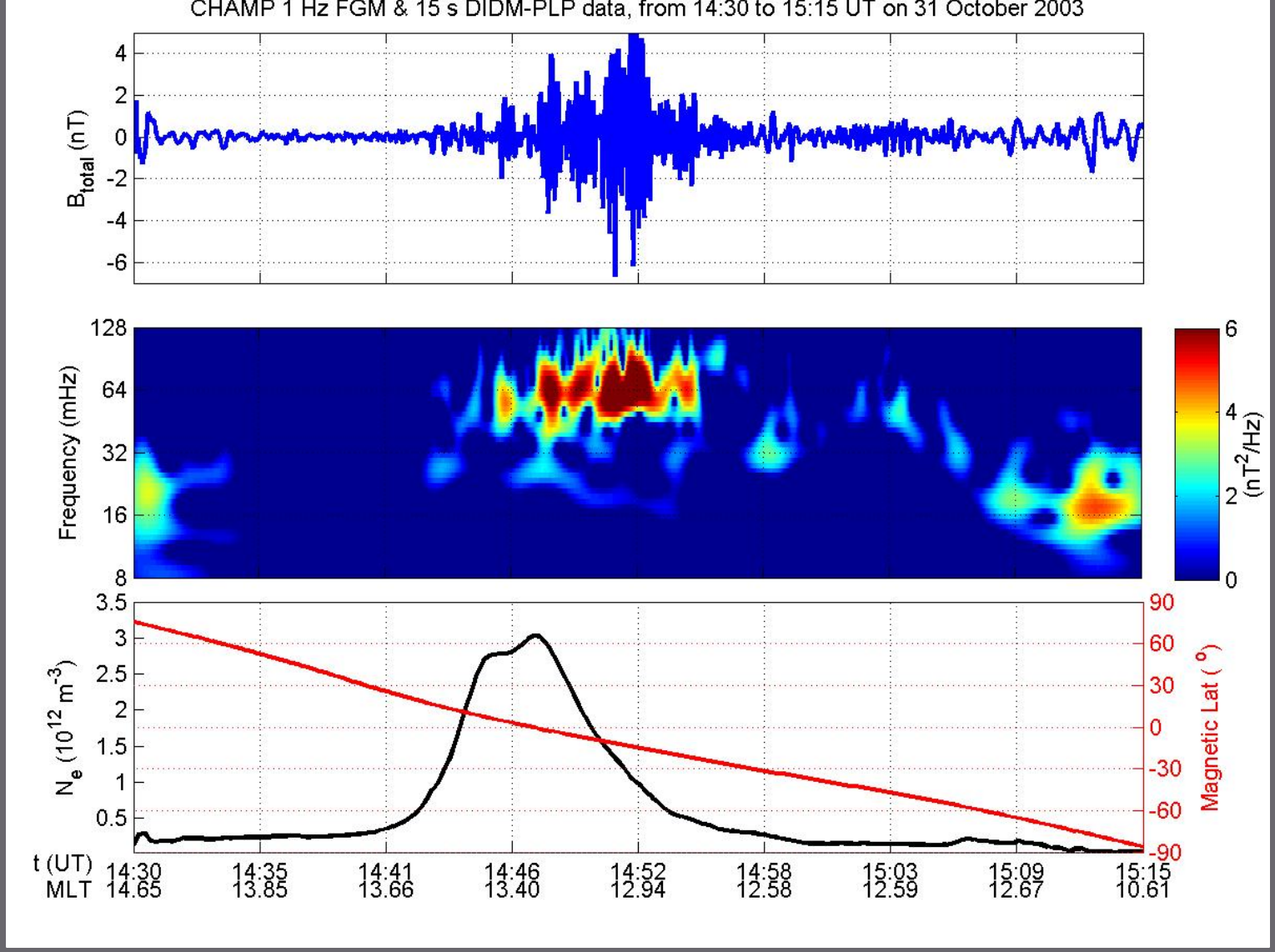
TFA: 3-Column Case

ESA's SWARM Mission



http://proteus.space.noa.gr/~ulf_wave/





Balasis et al. ULFwave activity during the 2003 Halloween superstorm: multipoint observations fromCHAMP, Cluster and Geotail missions,Ann. Geophys., 30, 1751-1768, doi:10.5194/angeo-30-1751-2012

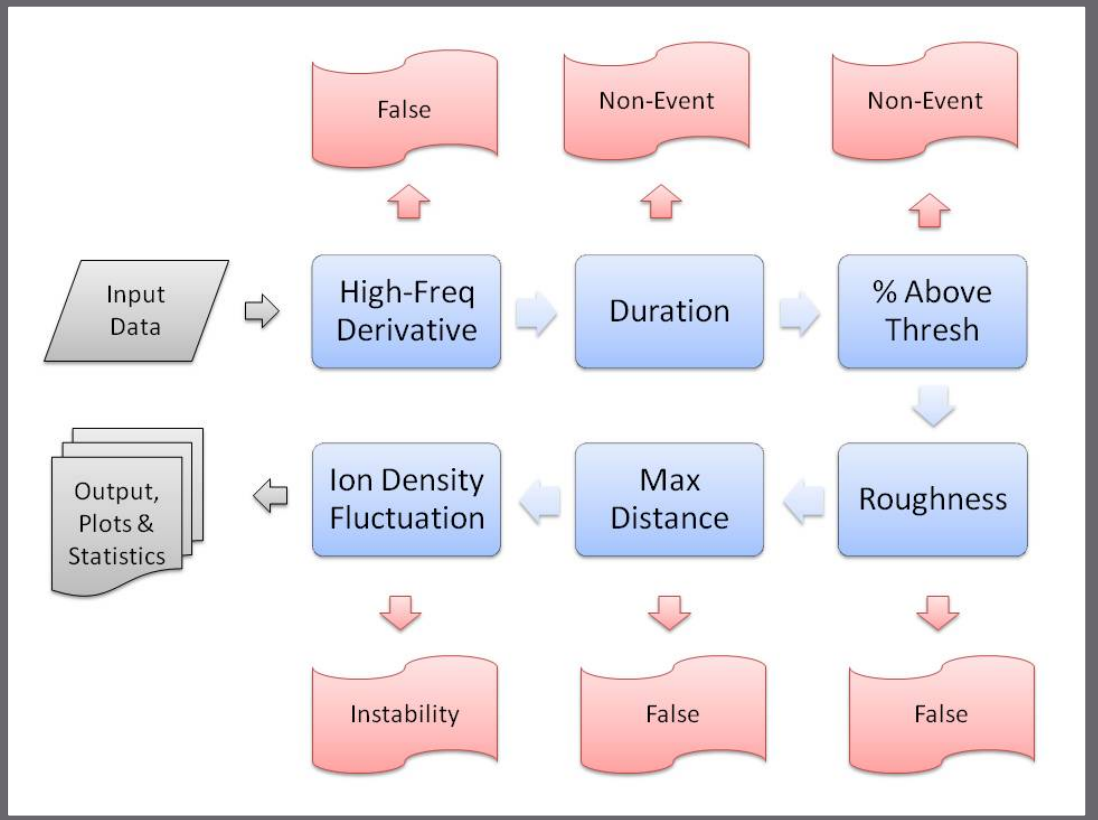
Automatic Event Detection

- Perform the Wavelet Analysis according to the current methodology
- Scan the wavelet spectrum along the temporal dimension
- Find consecutive times for which the wavelet power exceeds a certain threshold
- Mark these intervals as "Candidate Events" and extract important parameters
- Using the Classification Schema, examine if the Candidate passes all required tests to be marked as an actual Event
- In case of failure, identify the Candidate as a False Positive or Non-Event
- Plot the Track with the appropriate flags, classify it and save relevant statistics.

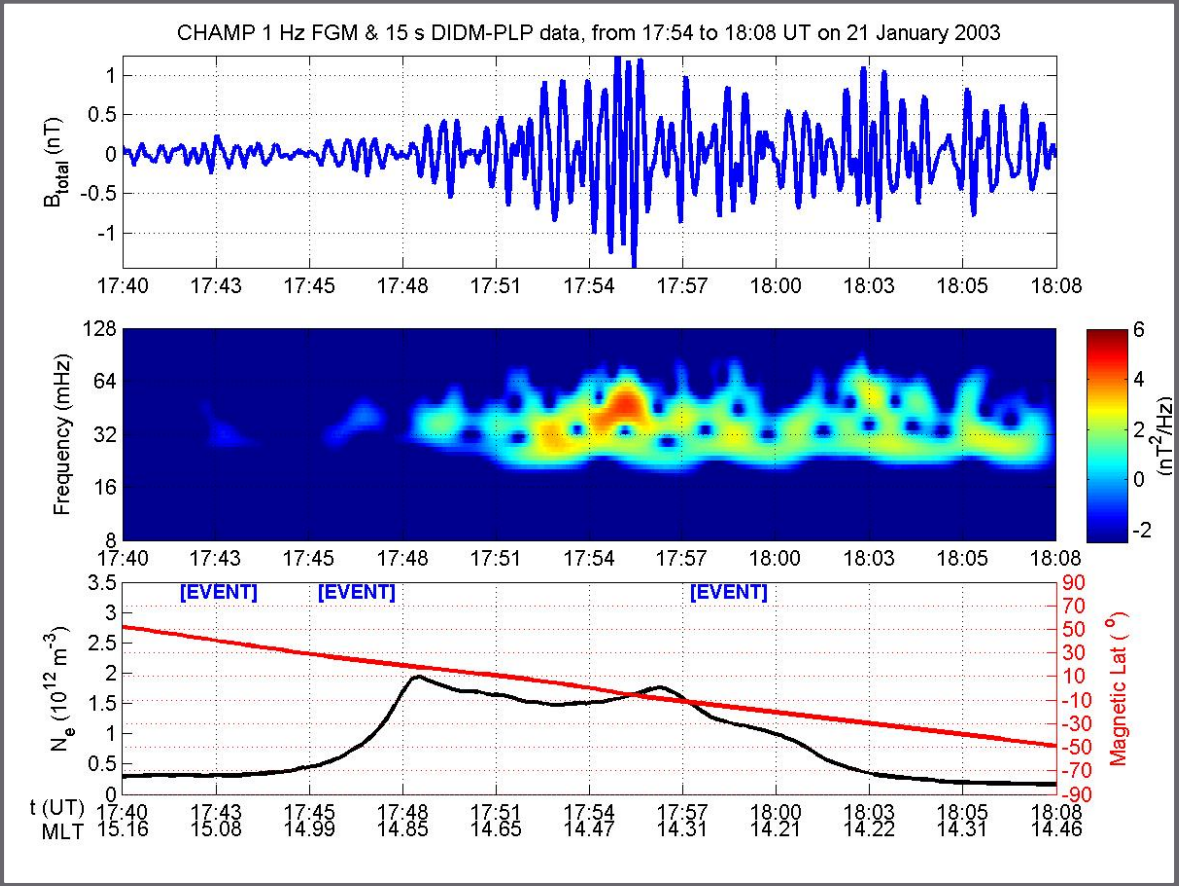
- Onset
- Duration
- Max Amplitude of the Filtered Signal
- Number of Points above a Threshold
- Peak Frequency
- Peak Frequency Power
- Time of Peak Frequency
- First Derivative of Wavelet Power at the Highest Frequency
- Frequency Range
- Total Wavelet Power
- Average Wavelet Power
- Signal Roughness
- Ion Density Roughness
- Magnetic Latitude
- Magnetic Local Time

Classification Schema

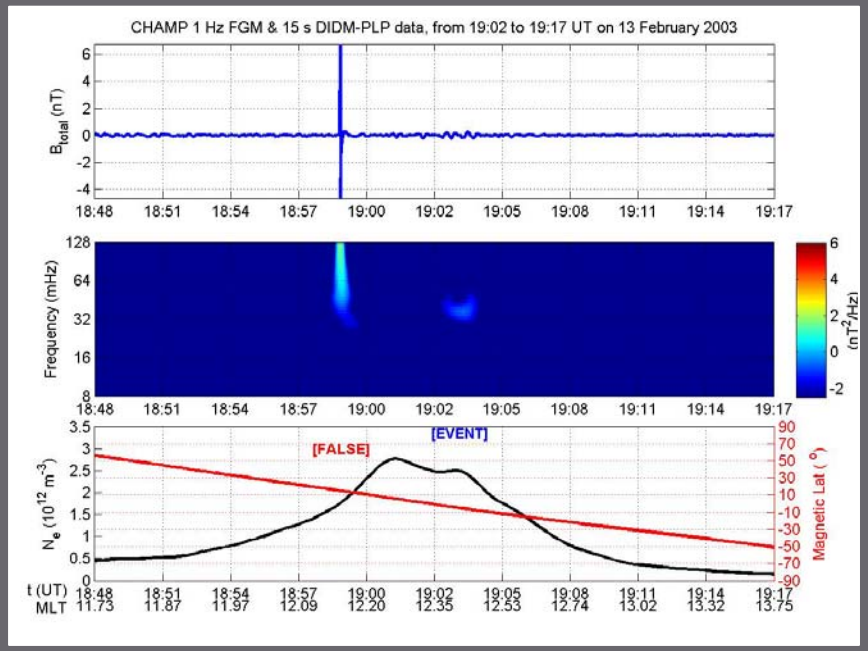
- **Input**: Candidate Segments, namely parts of the Track that exhibit activity greater than that attributed to background noise
- **Criteria**
- First time derivative of Wavelet Power at a frequency of 250 mHz
- Duration
- %of segment points that have values higher than the threshold
- Time series roughness (average absolute value of the second derivative at local extrema)
- Distance of maximum from mean, measured in standard deviations
- Roughness of the Ion Density time series

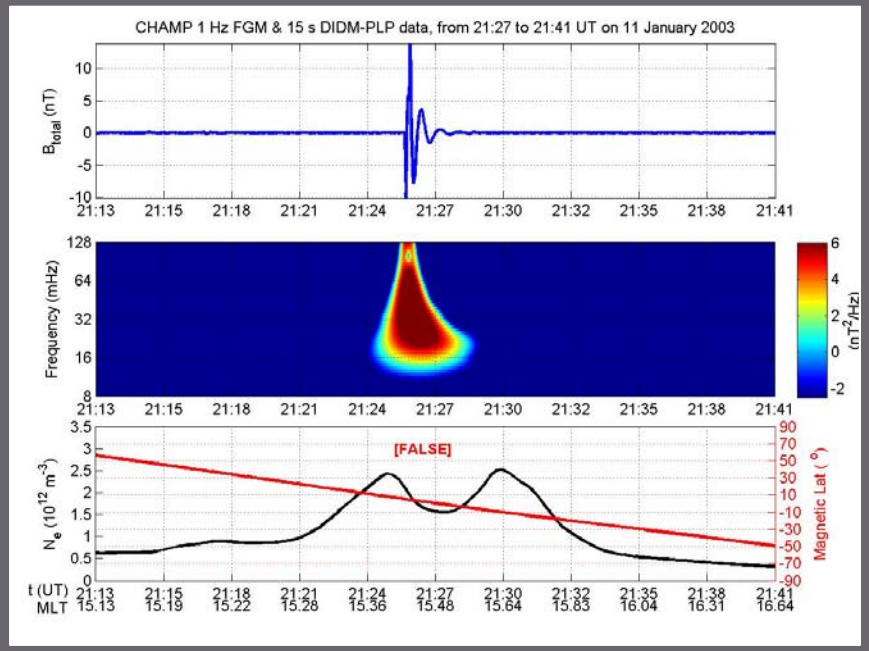


Example Case: Wave Events

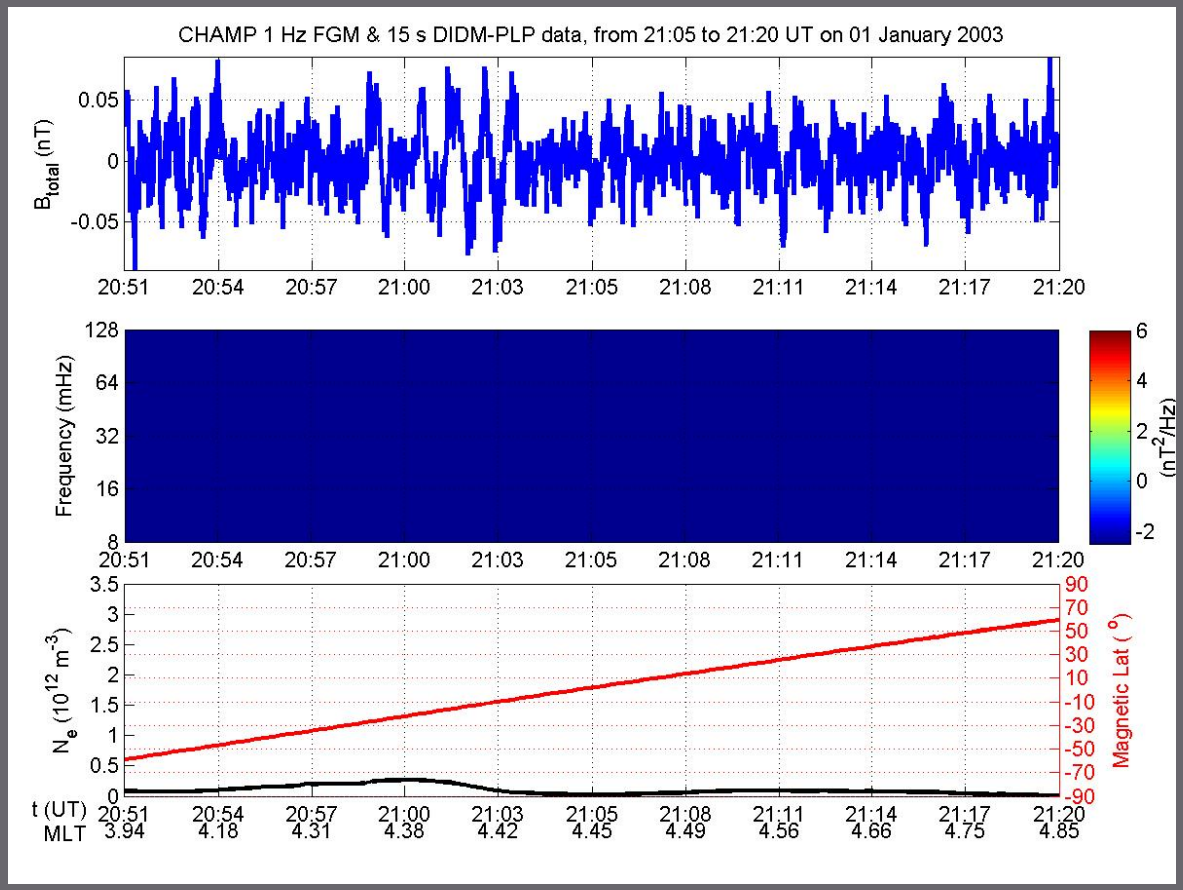


Example Cases: False Positives (spike & filter error)

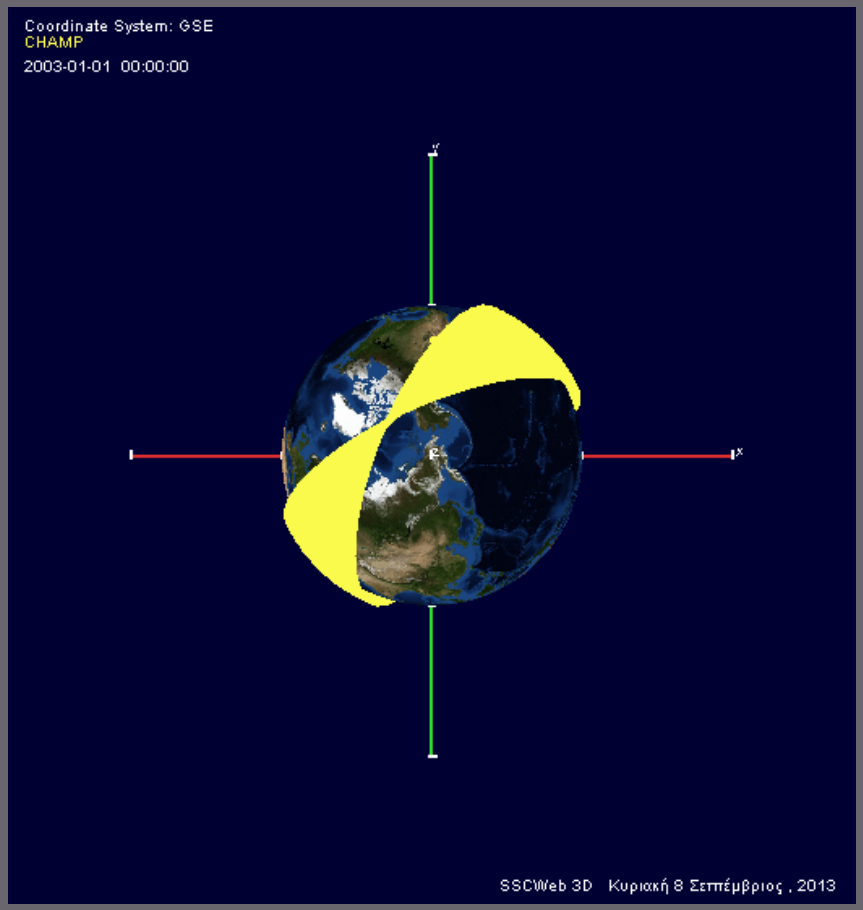




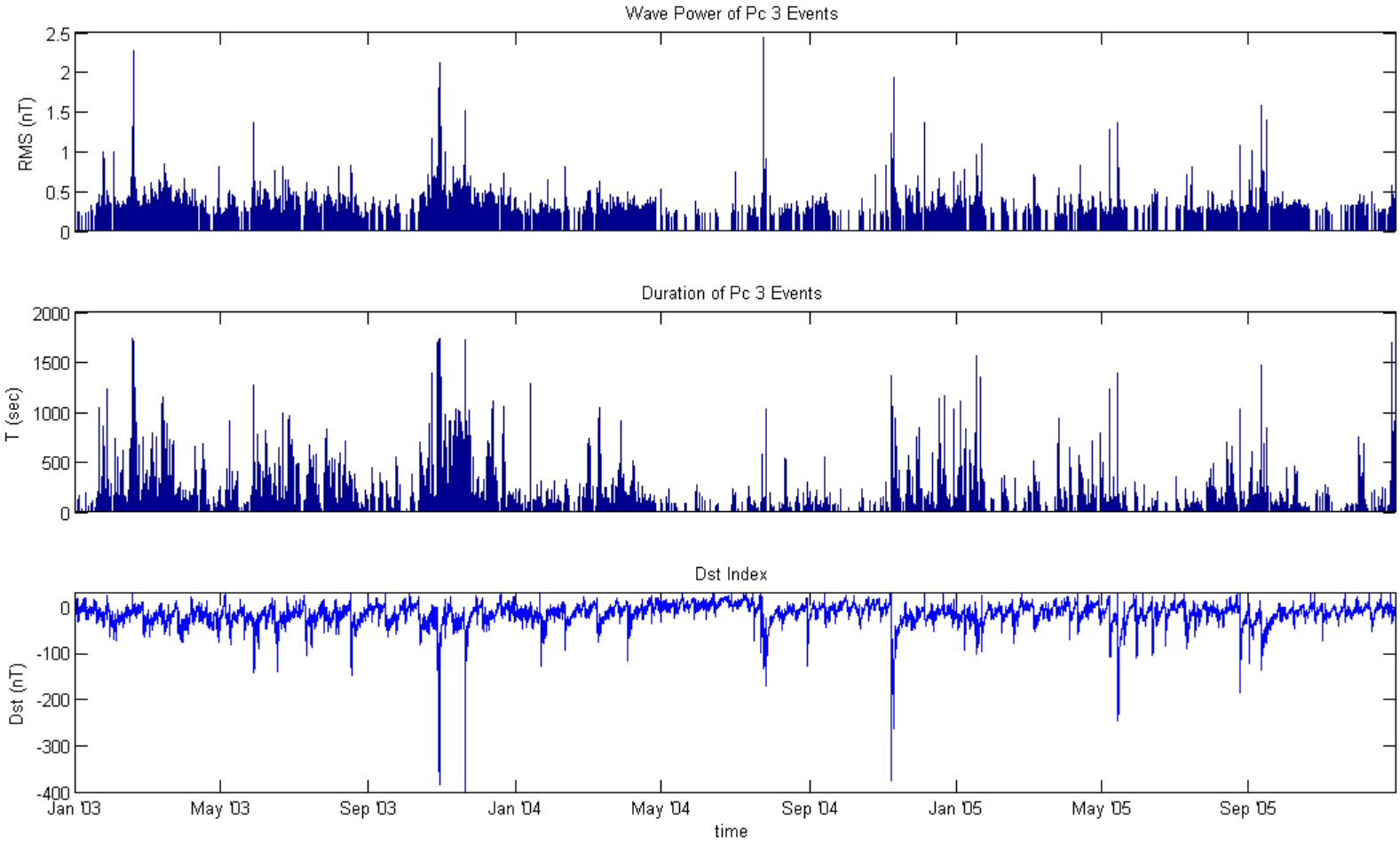
Example Case: Non – Event (background noise)

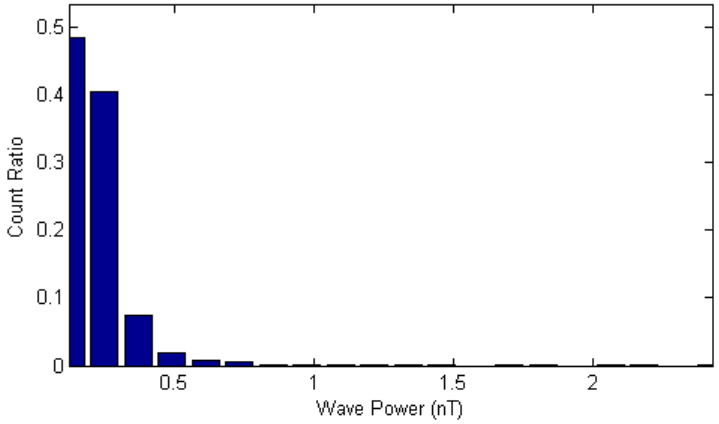


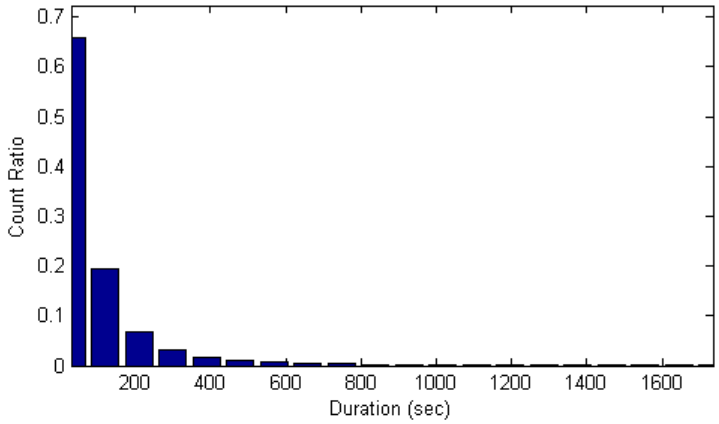
Dataset Description

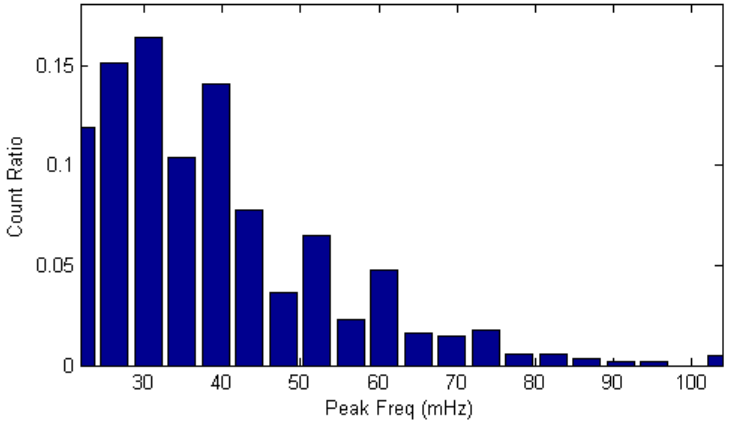


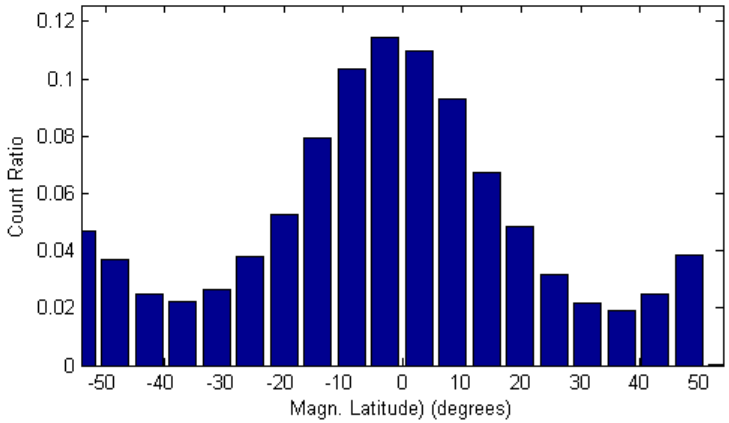
- 1 Hz magnetic field data (scalar)
- 15 sec ion density data
- Time span: 2003 – 2005
- > 33,000 Tracks
- Limited to [-55, +55] Mag. Lat.
- 11,461 Wave Events Detected
- Additional Data: OmniWeb Service http://omniweb.gsfc.nasa.gov/

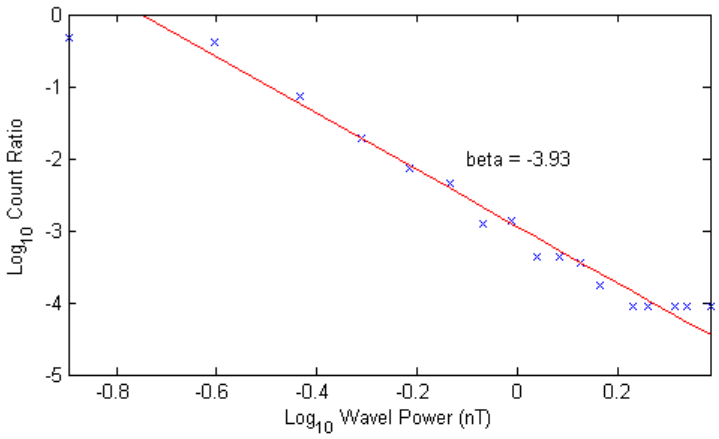

Wave Power of Pc 3 Events
RMS (nT)
2.5
2
1.5
1
0.5
0
Duration of Pc 3 Events
T (sec)
2000
1500
1000
500
0
Dst Index
Dst (nT)
0
-100
-200
-300
-400
Jan '03
May '03
Sep '03
Jan '04
May '04
Sep '04
Jan '05
May '05
Sep '05
time

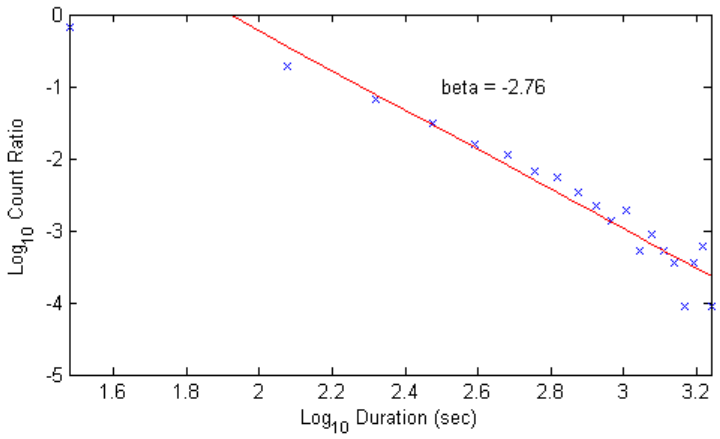

Count Ratio
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
Wave Power (nT)

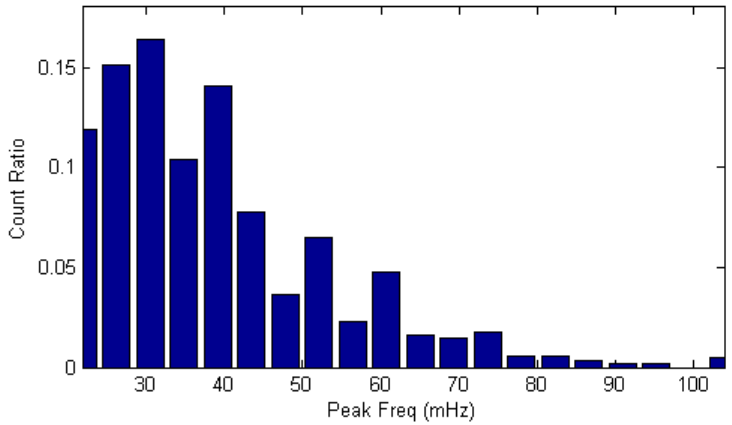

Count Ratio
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
400
600
800
1000
1200
1400
1600
Duration (sec)

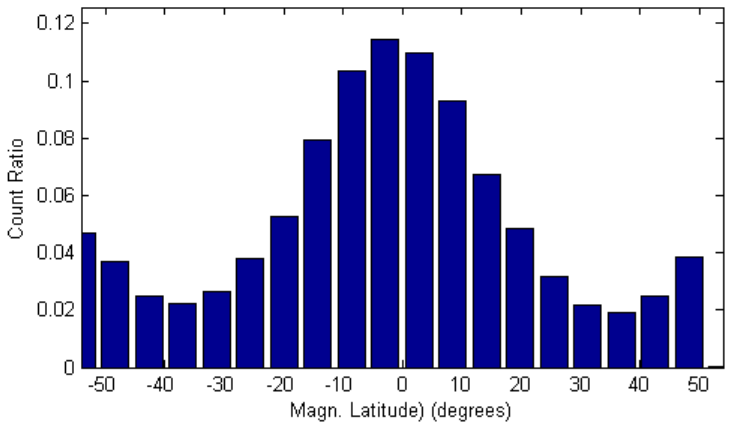

Count Ratio
0.15
0.1
0.05
0
30
40
50
60
70
80
90
100
Peak Freq (mHz)

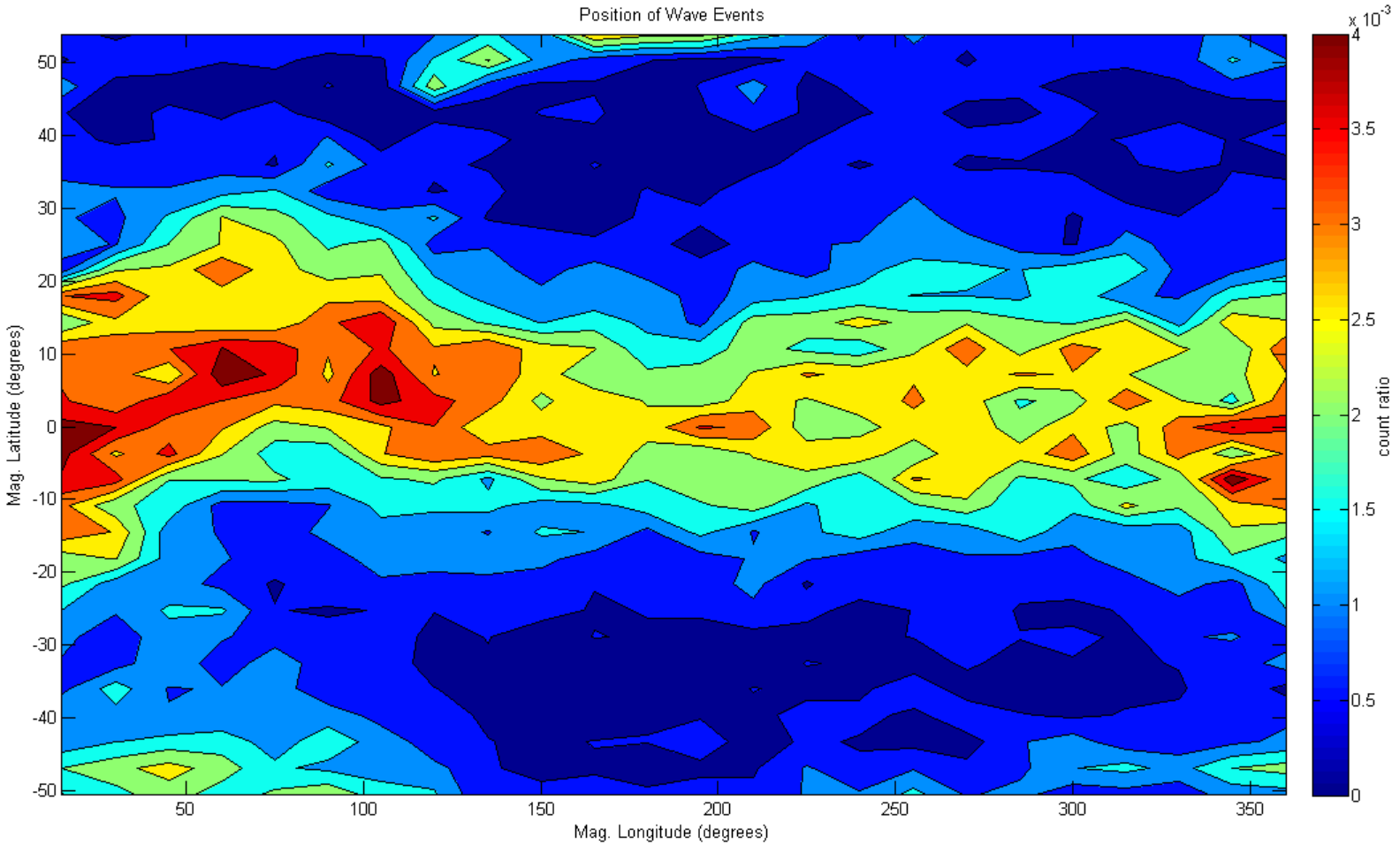

Count Ratio
0.12
0.1
0.08
0.06
0.04
0.02
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Magn. Latitude) (degrees)

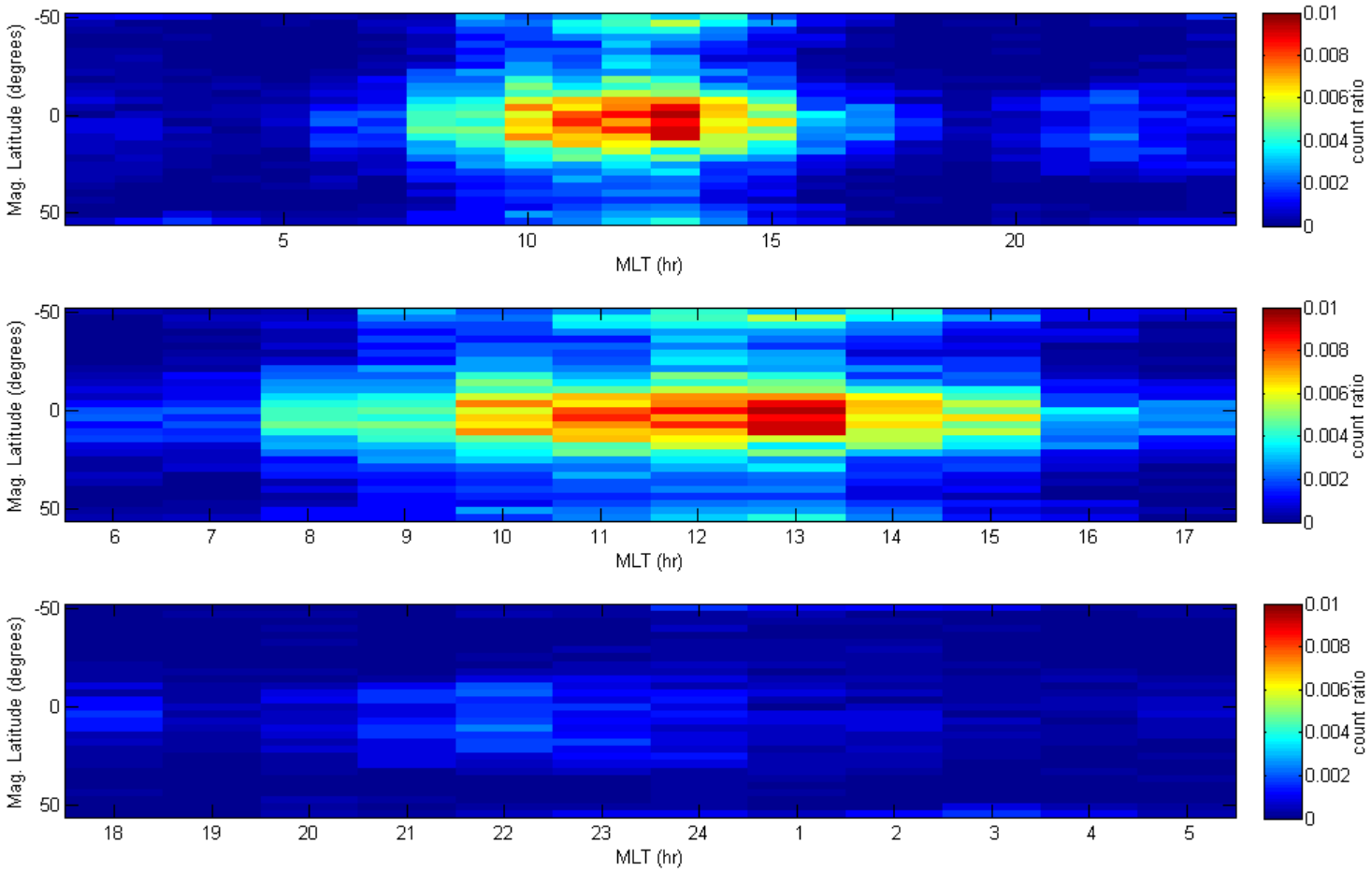

beta = -3.93
Log10 Count Ratio
Log10 Wavel Power (nT)


beta = -2.76
Log10 Count Ratio
Log10 Duration (sec)

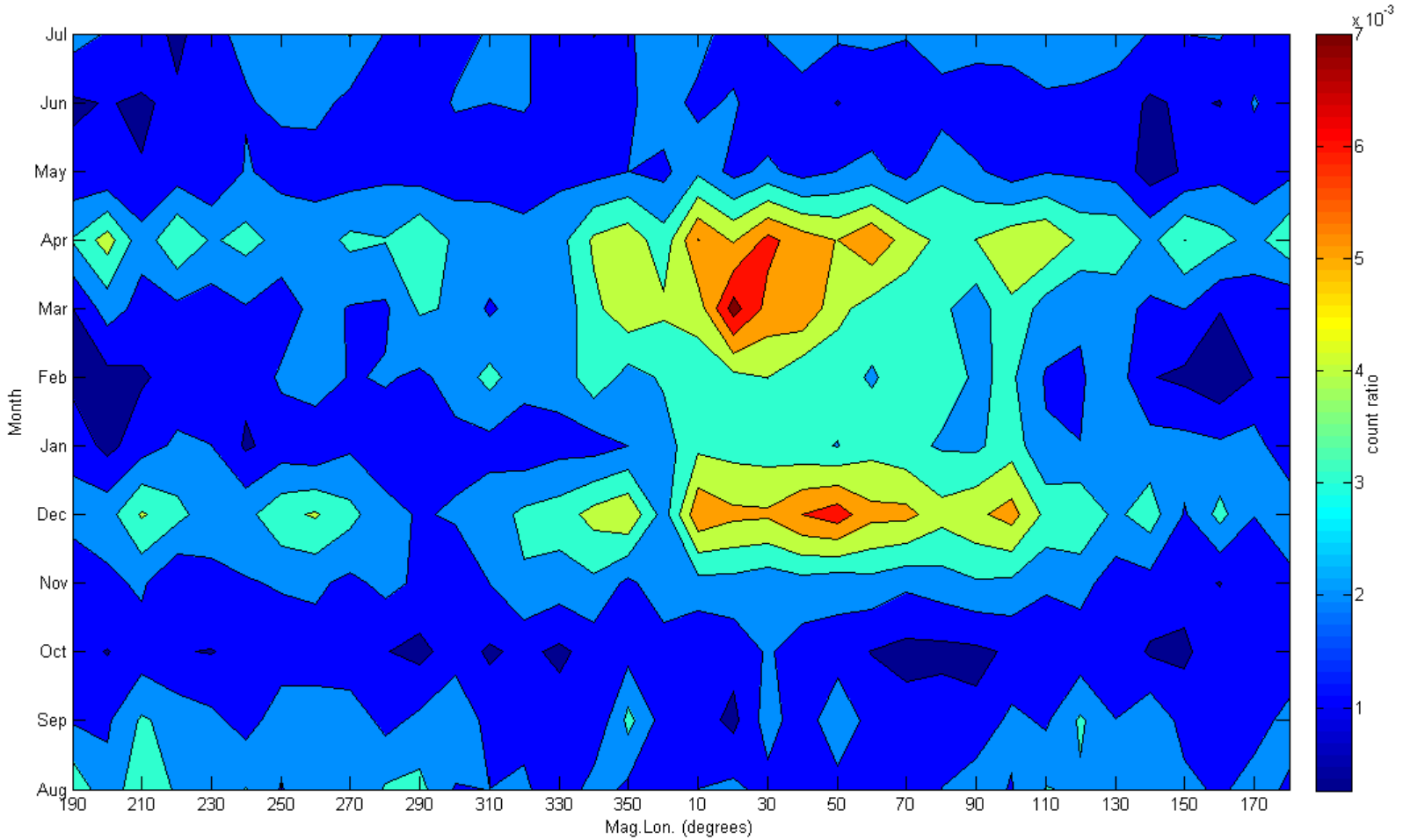

Count Ratio
Peak Freq (mHz)

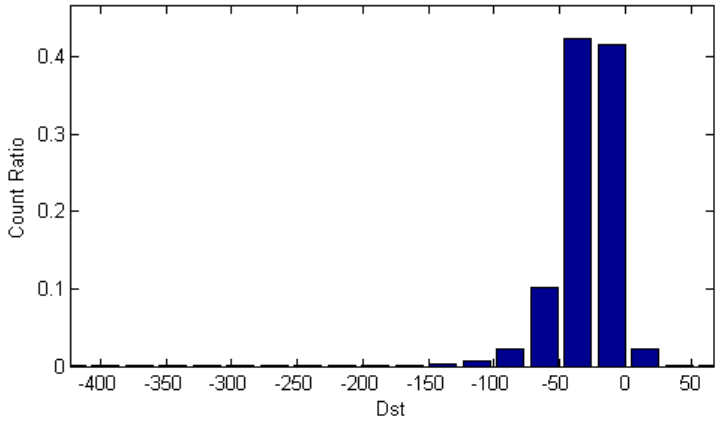

Count Ratio
Magn. Latitude) (degrees)

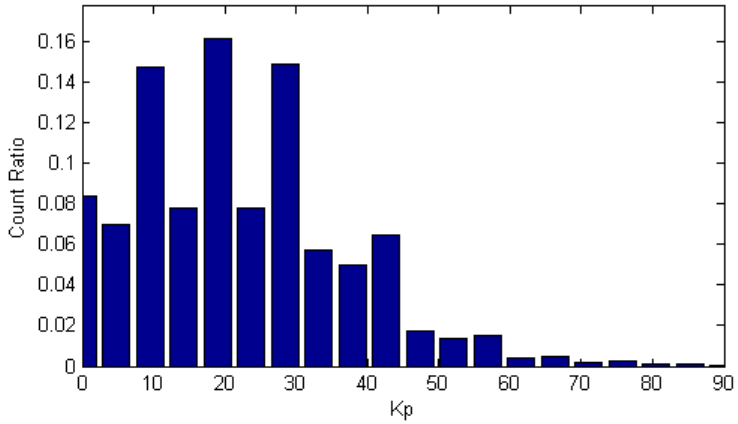

Position of Wave Events
Mag. Latitude (degrees)
Mag. Longitude (degrees)
count ratio
x 10^-3
50
40
30
20
10
0
-10
-20
-30
-40
-50
50
100
150
200
250
300
350
4
3.5
3
2.5
2
1.5
1
0.5
0

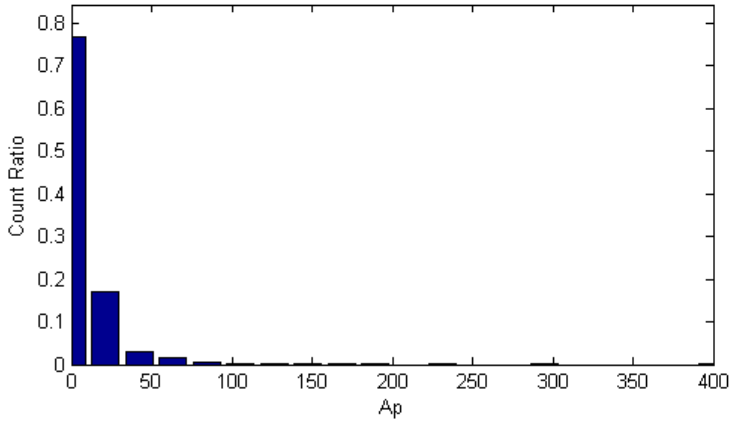


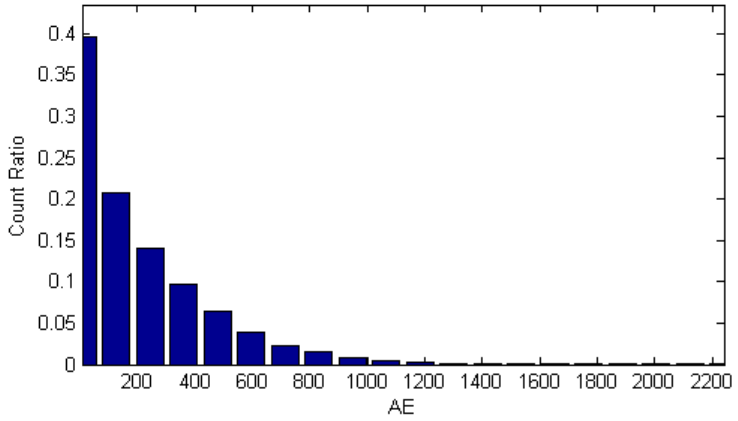
Day – Night variations in magnetic position of wave events


Jul
Jun
May
Apr
Mar
Feb
Jan
Dec
Nov
Oct
Sep
Aug
Month
190
210
230
250
270
290
310
330
350
10
30
50
70
90
110
130
150
170
Mag.Lon. (degrees)
x 10^-3
7
6
5
4
3
2
1
count ratio

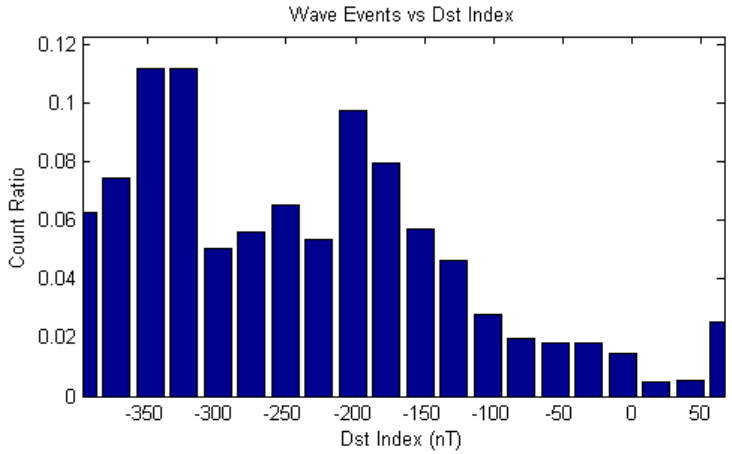


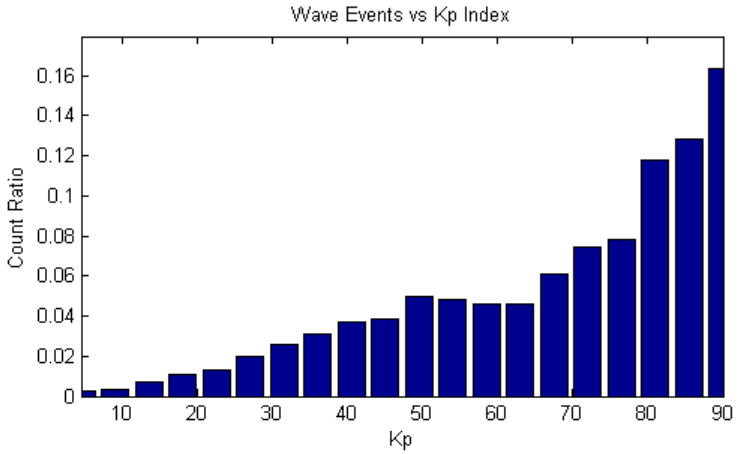


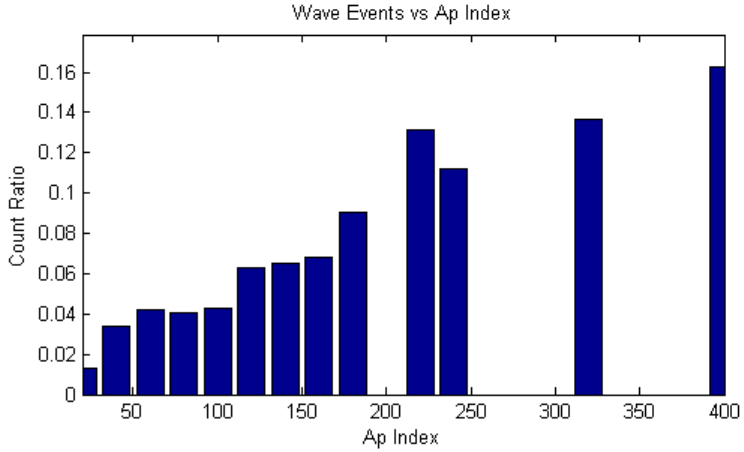


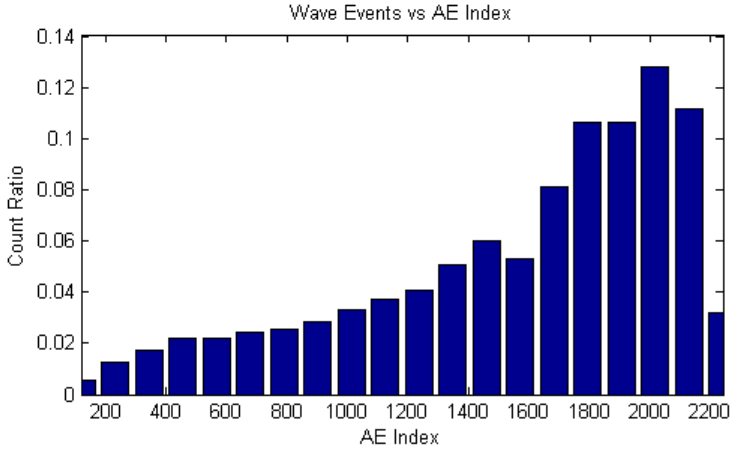


Distributions for the values of Geomagnetic Indices

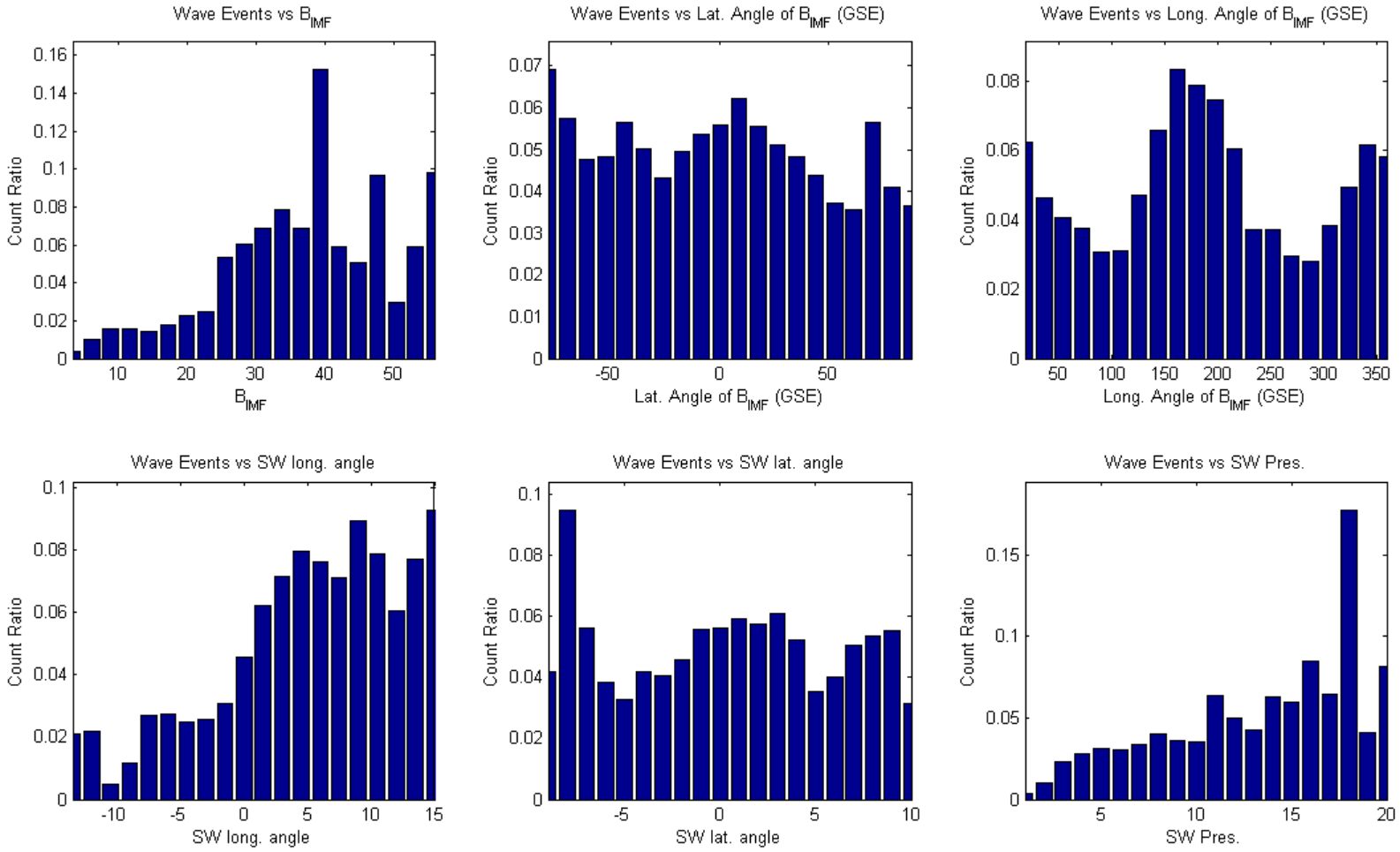




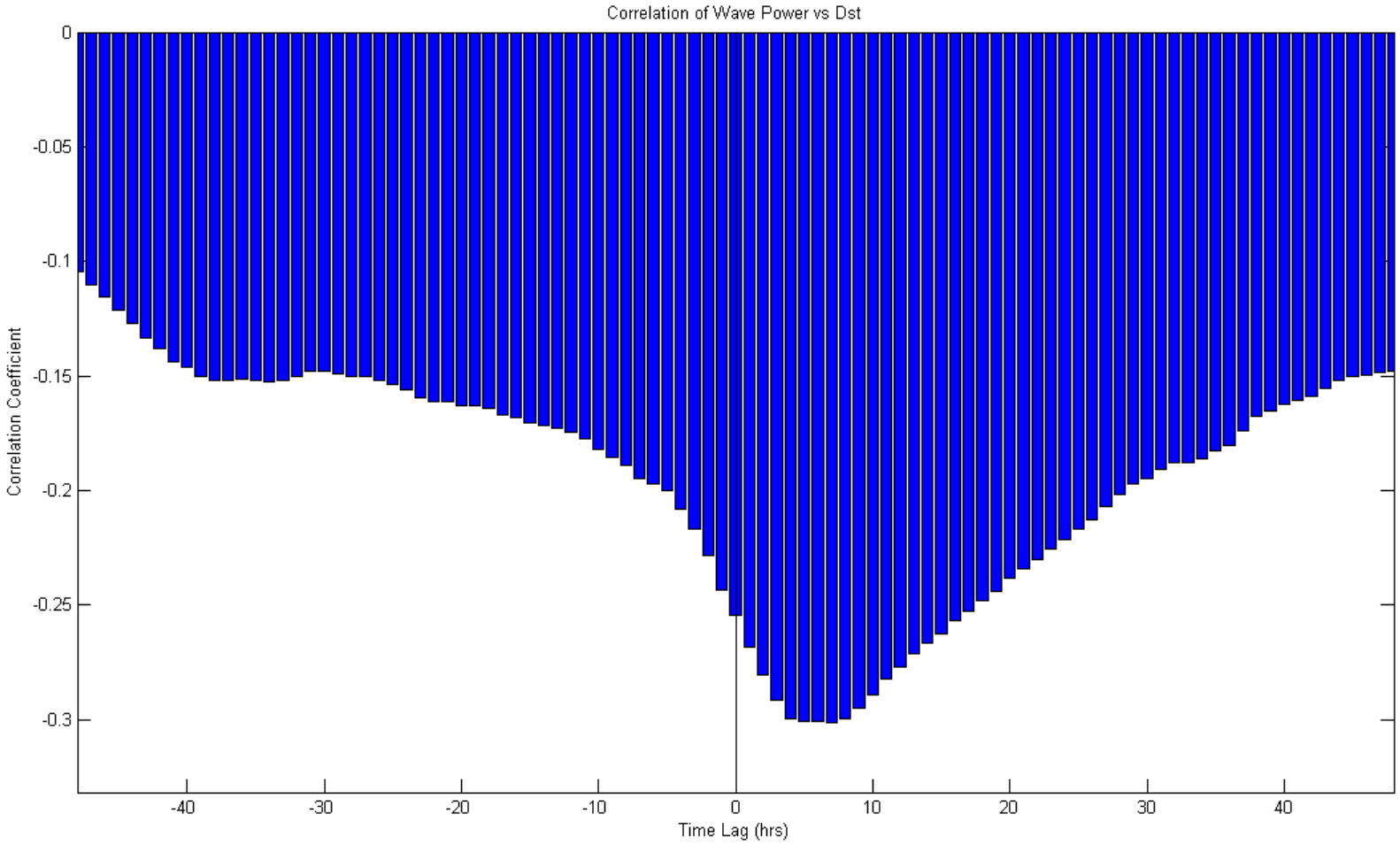




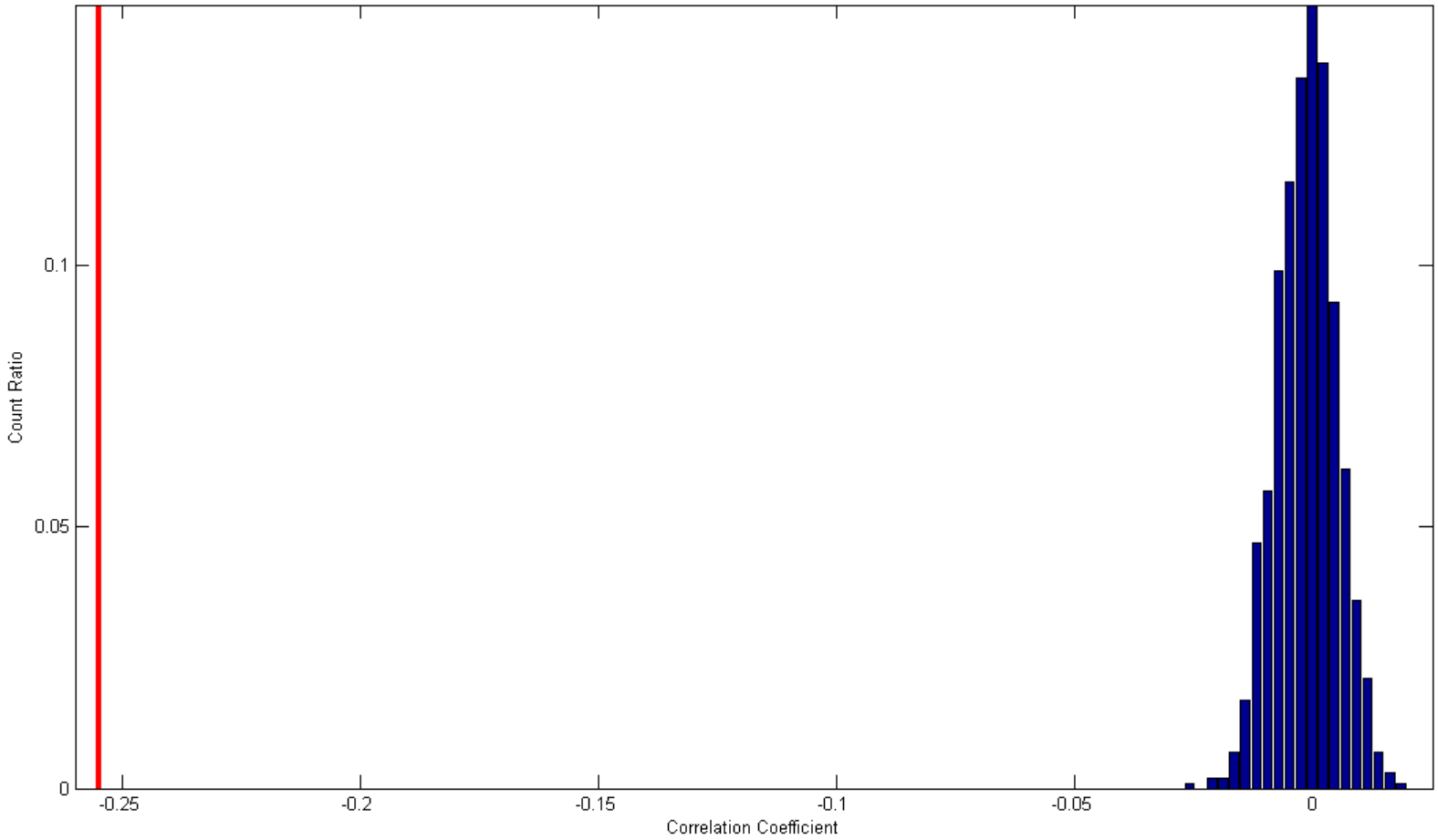
Wave Occurrence rates with respect to the values of various Indices



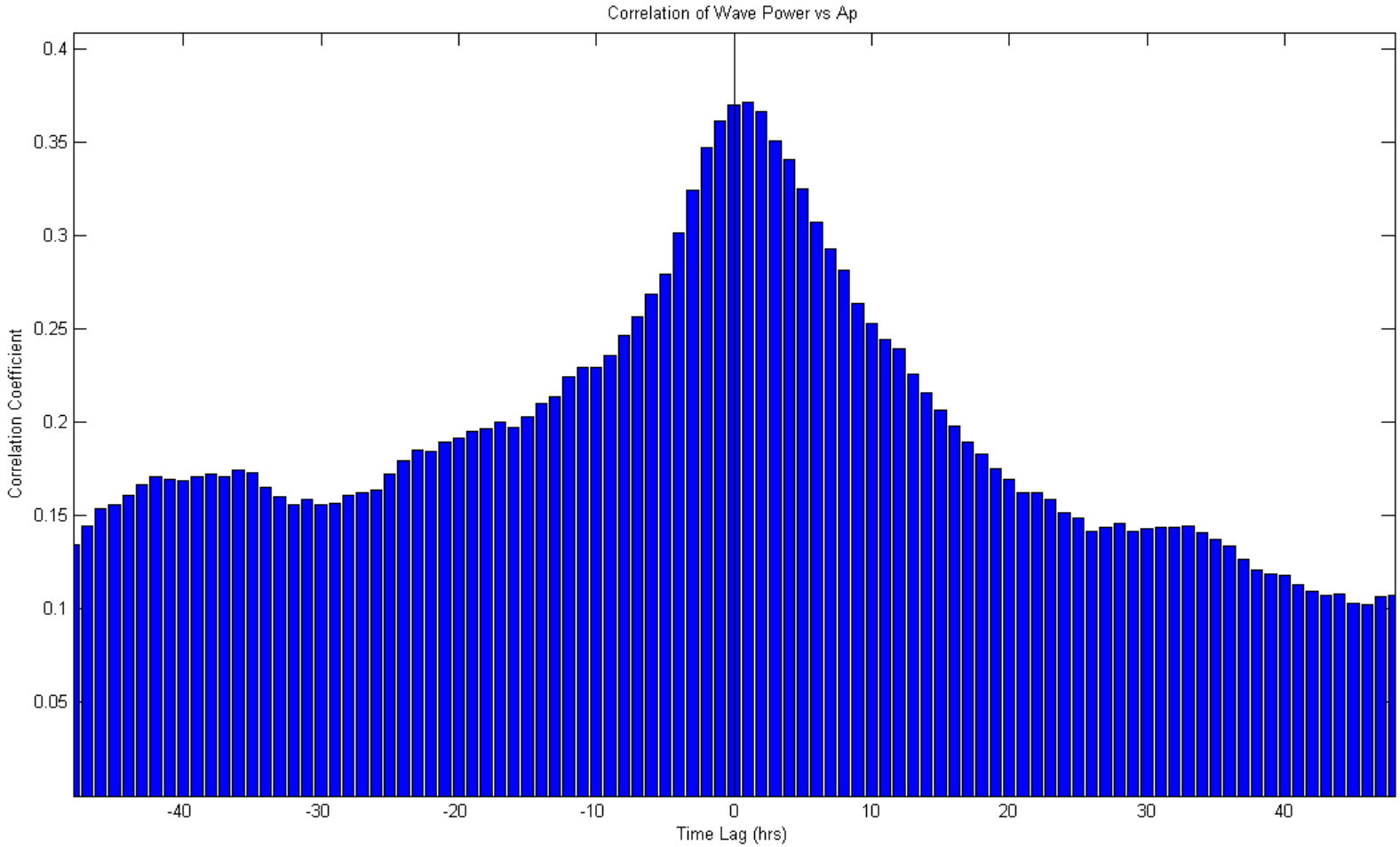
Wave Occurrence rates with respect to Solar Wind Parameters



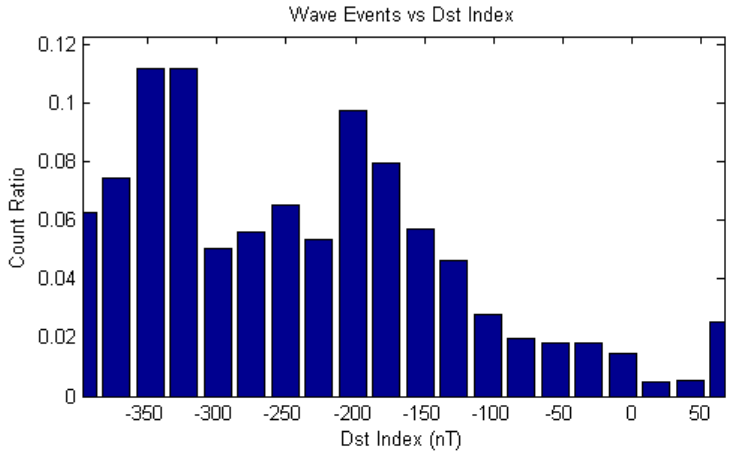
Time Shifted Correlation Coefficient of Wave Power Series vs Dst Index Series

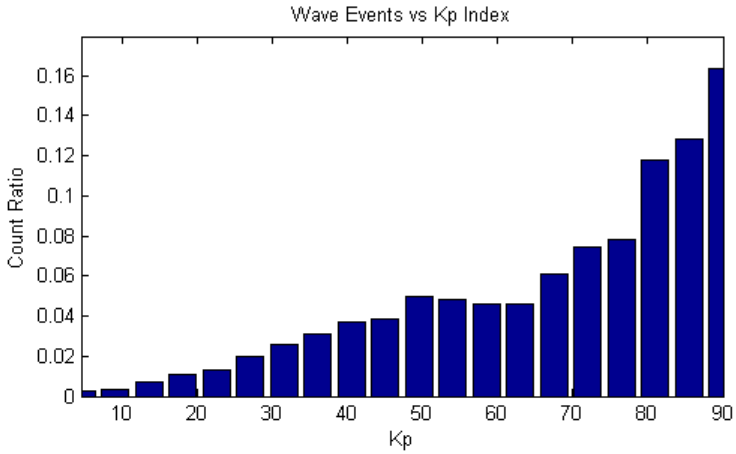


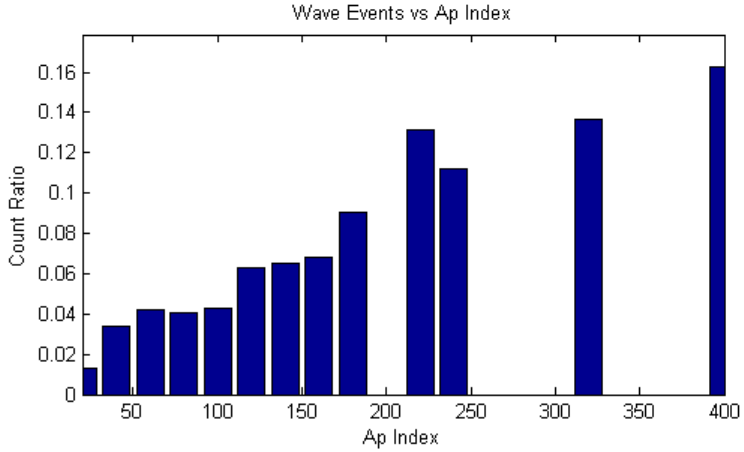
Distribution of Correlation Values for Shuffled Series (Wave Event Series vs Dst)

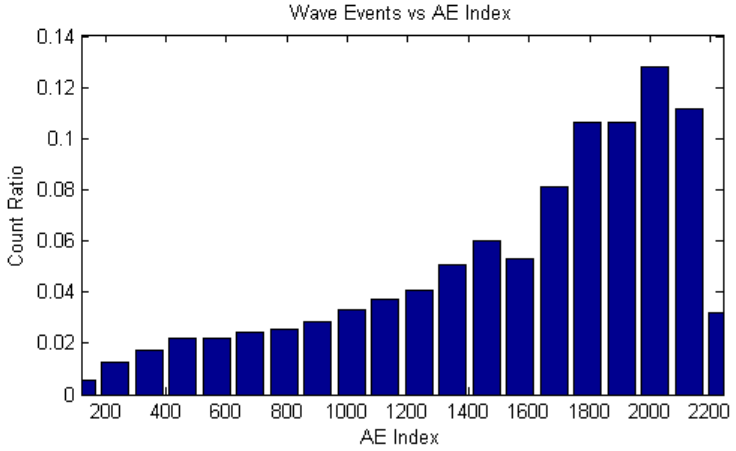


Time Shifted Correlation Coefficient of Wave Power Series vs Ap Index Series



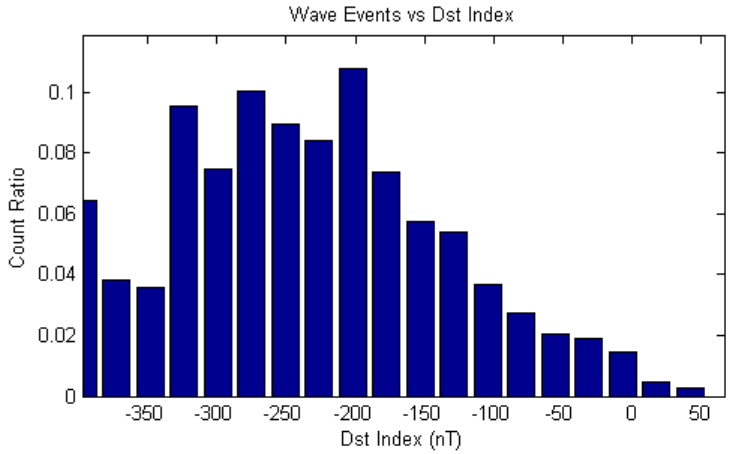


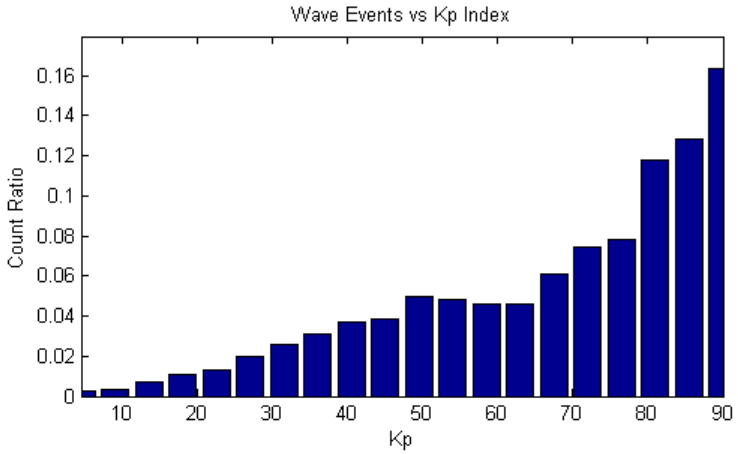


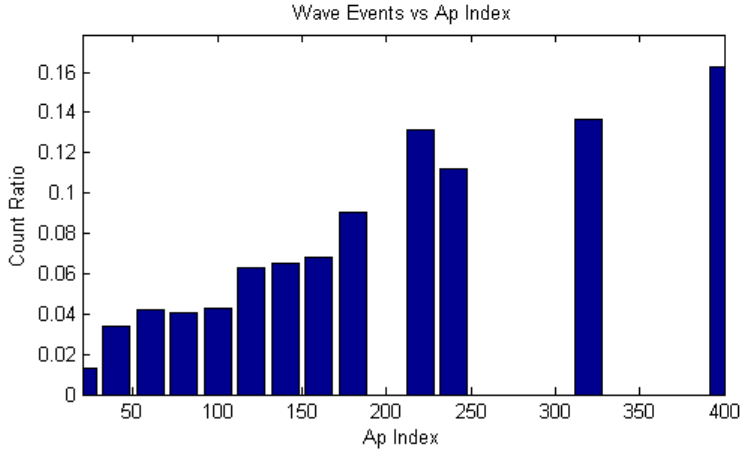


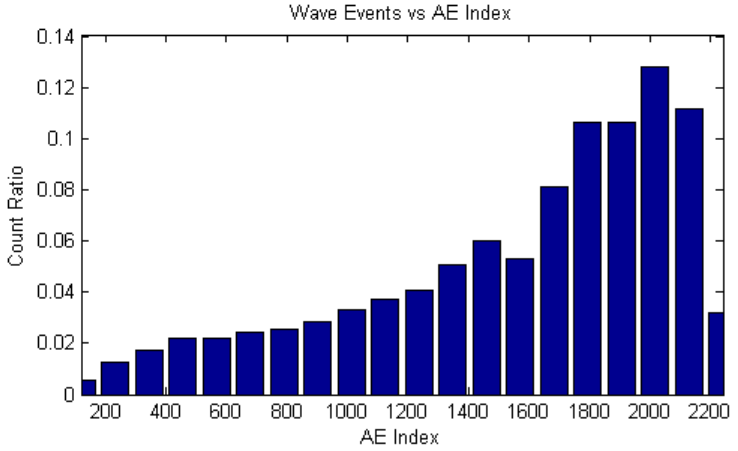
Wave Occurrence rates with respect to the values of various Indices

Dst Values shifted by – 7 Hrs!









Wave Occurrence rates with respect to the values of various Indices

Conclusions and Future Work

✓Statistics of Pc3 ULF Waves for a 3 year period (location, physical properties). Previous studies extend only up to a few months.

✓Correlations with geomagnetic conditions

✓Correlations with solar wind parameters

Future Work:

Further Classification of waves according to their power or physical characteristics.

ULF & VLF Wave Role in Relation to energetic particles (energization / losses)