1. Global Observations of ULF Power by ULTIMA

2. Observations of High-m Poloidal Waves by ST-5 Satellites

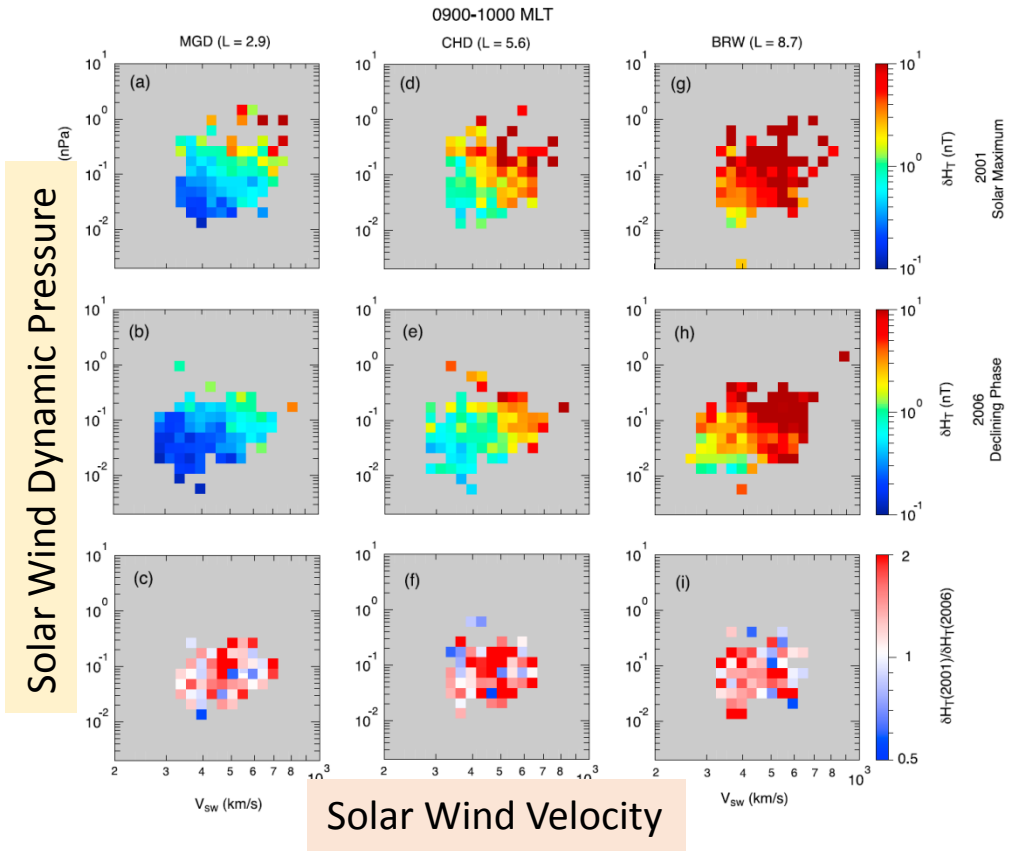
Peter J. Chi [1,2]

1. Earth Planetary and Space Sciences, UCLA

2. Goddard Space Flight Center, NASA

2015 GEM Summer Workshop
Metrics and Validation Focus Group
Snowmass, Colorado

Solar Wind Control of ULF Waves



- Statistical analyses of solar wind control of ULF (such as Pc5) power has been conducted extensively.
- Solar wind parameters can explain only up to ~60% of Pc5 power

Left: Takahashi et al. (2012)

Bottom: Simms et al. (2010)

Table 4. Unstandardized Coefficients of the Multiple Regression Analyses[a]

Storm Type	Storm Phase	b_0	$\log_{10} T_{IMF}$	$\log_{10} T_N$	$Dst/10$	$N/10$	$V/100$	$Bz/10$	Lag $\log_{10} T_{GR}$	R^2	r
CME	Initial	0.719	0.118	0.550	−0.022	−0.052	0.069	−0.181	0.421	0.647	0.804
CME	Main	0.545	0.024	0.073	−0.001	0.004	0.046	−0.116	0.504	0.535	0.732
CME	Recovery	0.271	0.056	0.144	−0.004	0.027	0.067	−0.194	0.586	0.637	0.798
CME	After recovery	−0.029	0.067	0.117	−0.020	0.077	0.114	−0.239	0.561	0.644	0.803
CIR	Initial	0.264	0.114	0.114	−0.028	0.013	0.112	−0.256	0.431	0.431	0.657
CIR	Main	0.168	0.062	0.073	−0.001	0.035	0.080	−0.194	0.566	0.624	0.790
CIR	Recovery	0.202	0.053	0.099	−0.009	0.010	0.094	−0.312	0.507	0.510	0.714
CIR	After recovery	0.085	0.129	0.050	−0.026	0.076	0.084	−0.315	0.535	0.588	0.767
Quiet		0.008	0.104	0.083	−0.033	0.075	0.104	−0.365	0.538	0.637	0.798
All		0.067	0.098	0.079	−0.010	0.043	0.091	−0.271	0.574	0.674	0.821

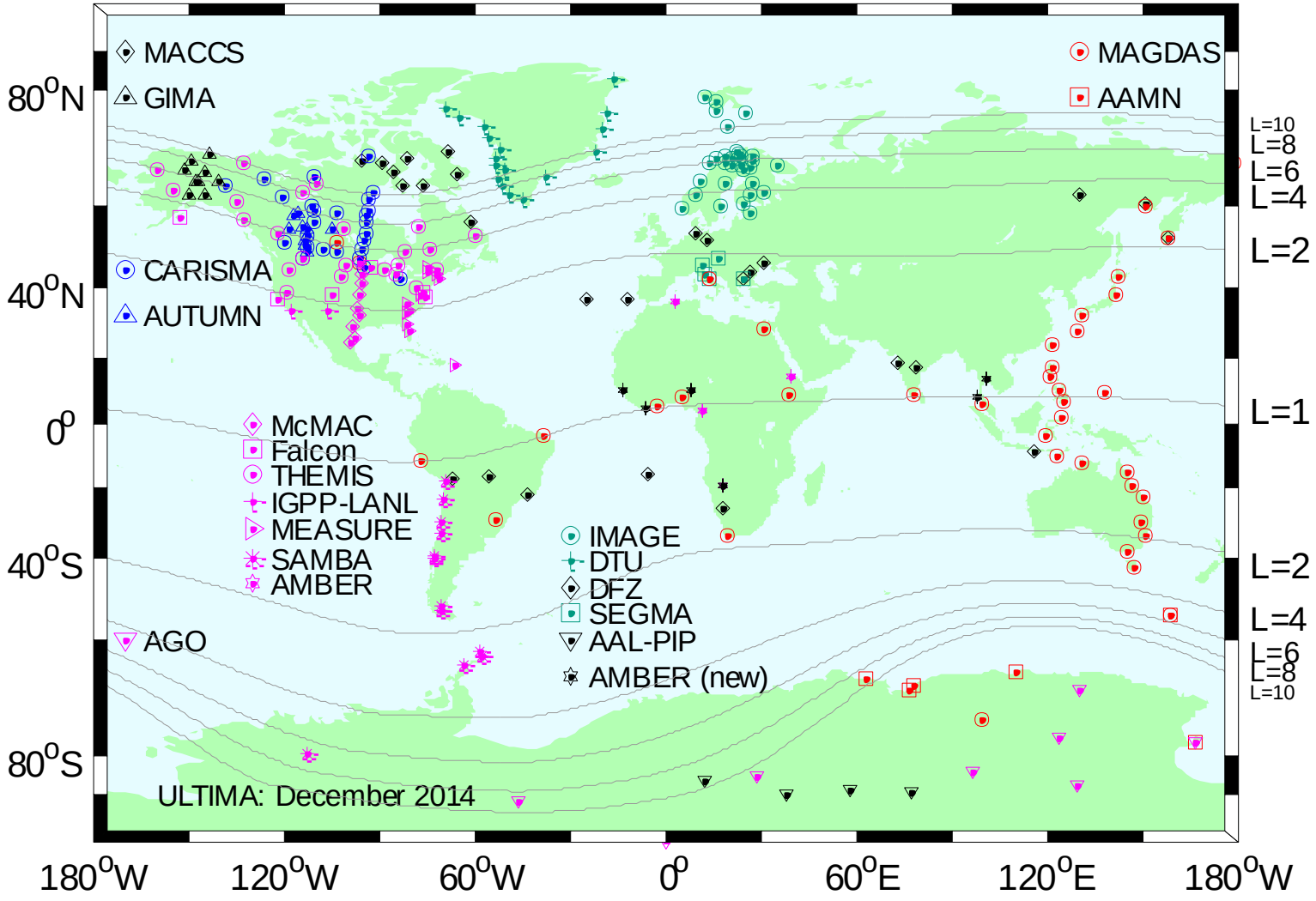
[a]$\log_{10} T_{GR}$ is the dependent variable.

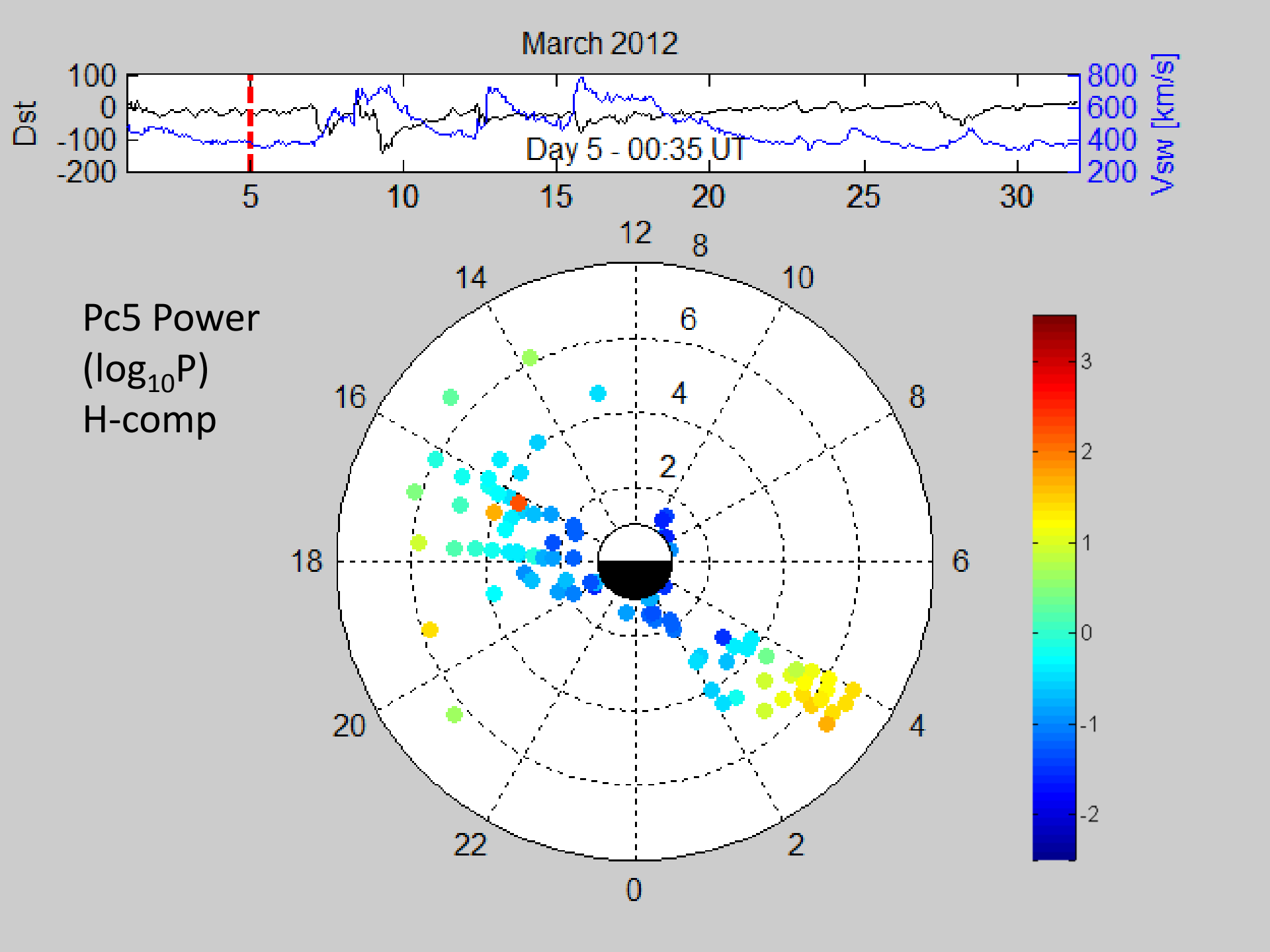
ULF Meteorology: A Proposition

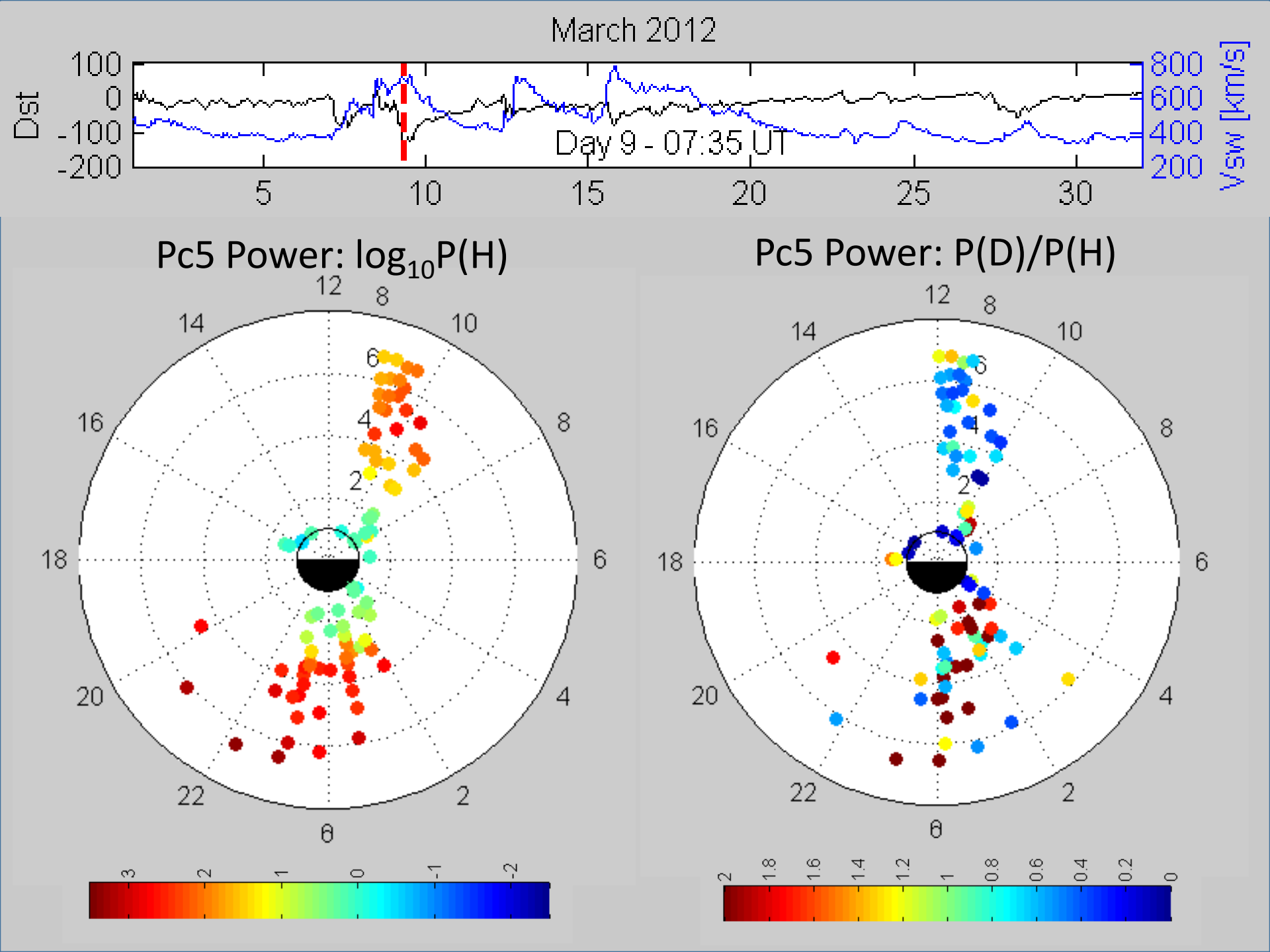
- Climatological studies of ULF waves have their limits.
- ULF waves are more complicated. Factors such as field line resonance are difficult to be included in statistical analysis.
- ULF waves are highly dependent on location [e.g., *Rae et al.*, 2012; *Takahashi et al.*, 2012]
- The interest in ULF waves interacting with radiation belt electrons calls for meteorological studies of ULF waves, which requires a large network of magnetic observatories.

Ultra Large Terrestrial International Magnetometer Array

(17 member arrays; 250+ stations)




March 2012
Dst
100
0
-100
-200
Day 5 - 00:35 UT
5
10
15
20
25
30
800
600
400
200
Vsw [km/s]
Pc5 Power
(log10P)
H-comp
12
8
14
10
6
16
4
8
2
18
6
20
4
22
2
0
3
2
1
0
-1
-2


March 2012
Dst
100
0
-100
-200
5
10
15
20
25
30
Day 9 - 07:35 UT
800
600
400
200
V'sw [km/s]
Pc5 Power: log10P(H)
Pc5 Power: P(D)/P(H)
12
8
14
10
16
6
4
18
2
20
22
0
3
2
1
0
-1
-2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

Some Meteorological Characteristics of Pc 5 Power

- Temporal variation: The Pc 5 power can vary by more than 5 orders of magnitude between quiet times and storm times.
- Spatial variation: The enhancement in wave power can vary considerably across the globe.
- Solar wind influence: In the storm event, the Pc 5 wave power at *Dst* maximum (as a result of enhanced solar wind pressure) peaked at highest latitudes.
- Storm-time: In comparison, the Pc 5 wave power at *Dst* minimum (i.e., main phase) was the strongest at auroral/sub-auroral latitudes. (*penetration of wave power*)
- Wave mode: Wave power enhancement in ***D*-component** highly depends on location and may be sporadic.
- Quiet-time: ULF power can reach the storm-time level during non-storm time.

2. Observations of "Another Type" of ULF Waves

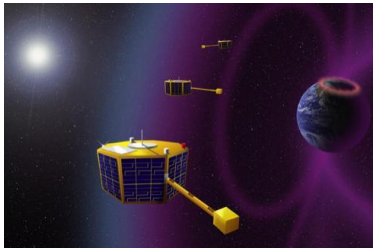
Peter J. Chi [1,2] and Guan Le [2]

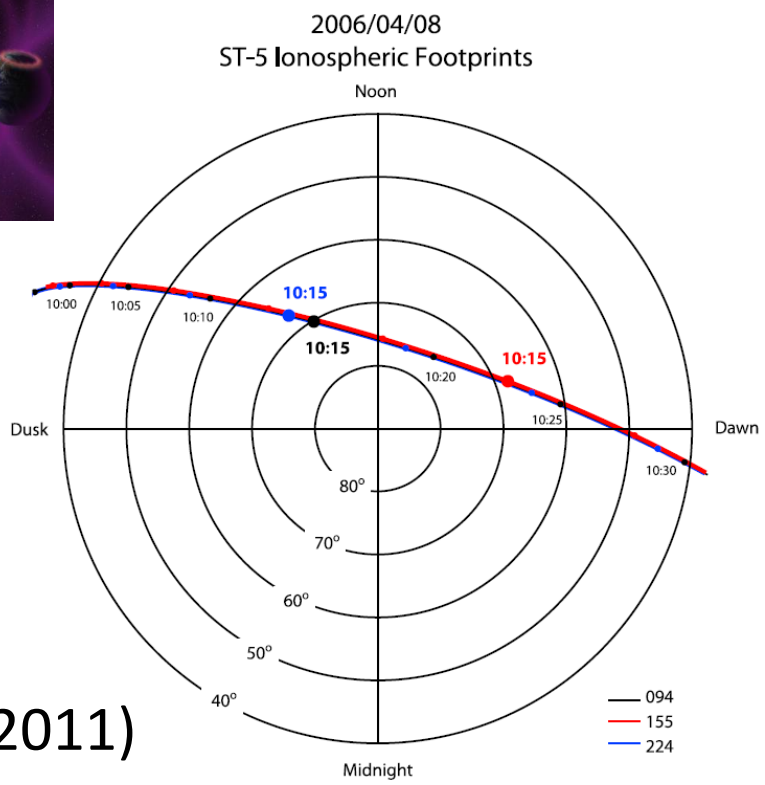
1. Earth Planetary and Space Sciences, UCLA

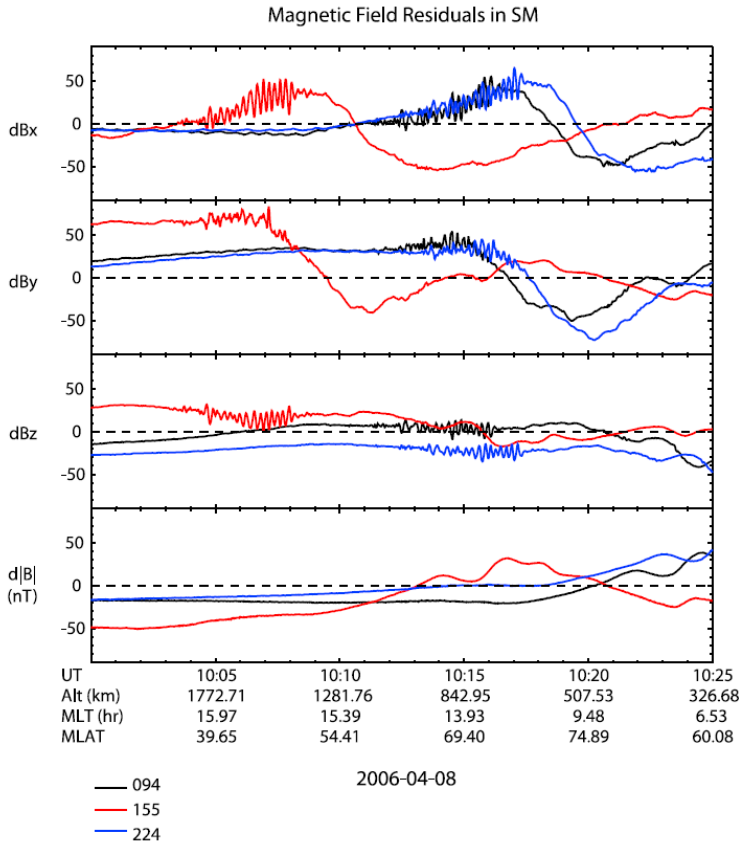
2. Goddard Space Flight Center, NASA

ST5 Observations of Pc2 Waves

- ST5 was a 3-satellite NASA mission with (1) a "pearls-on-a-string" configuration and (2) an unusual orbit (105.6° inclination).
- Waves with periods of 10 - 20 s were observed on many orbits.

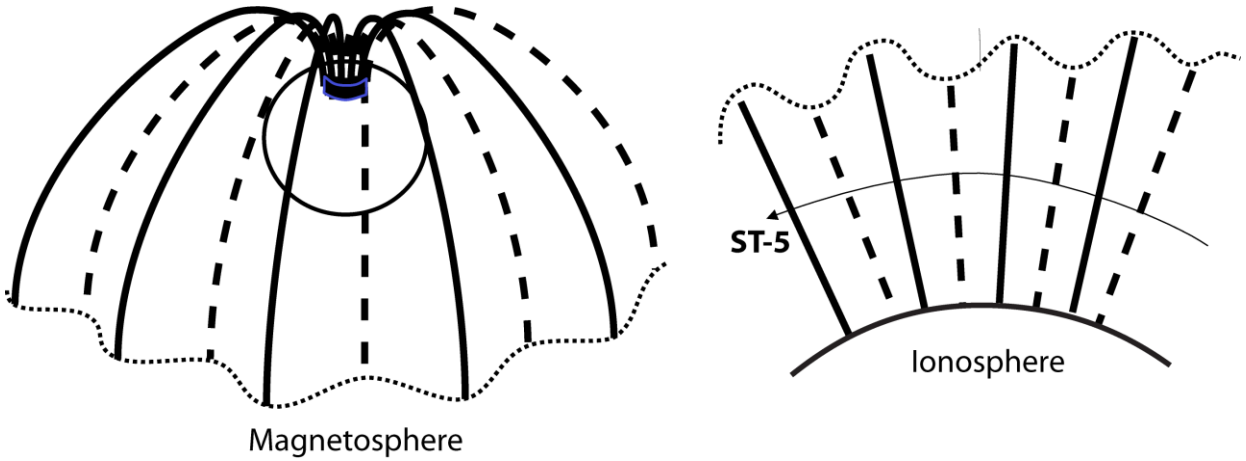






Le et al. (2011)

High-*m* Poloidal ULF Waves



Doppler Effect

$$f_{sc} = f_E - \frac{m}{2\pi}\left(\frac{d\theta}{dt}\right)$$

When $f_E << f_{sc}$

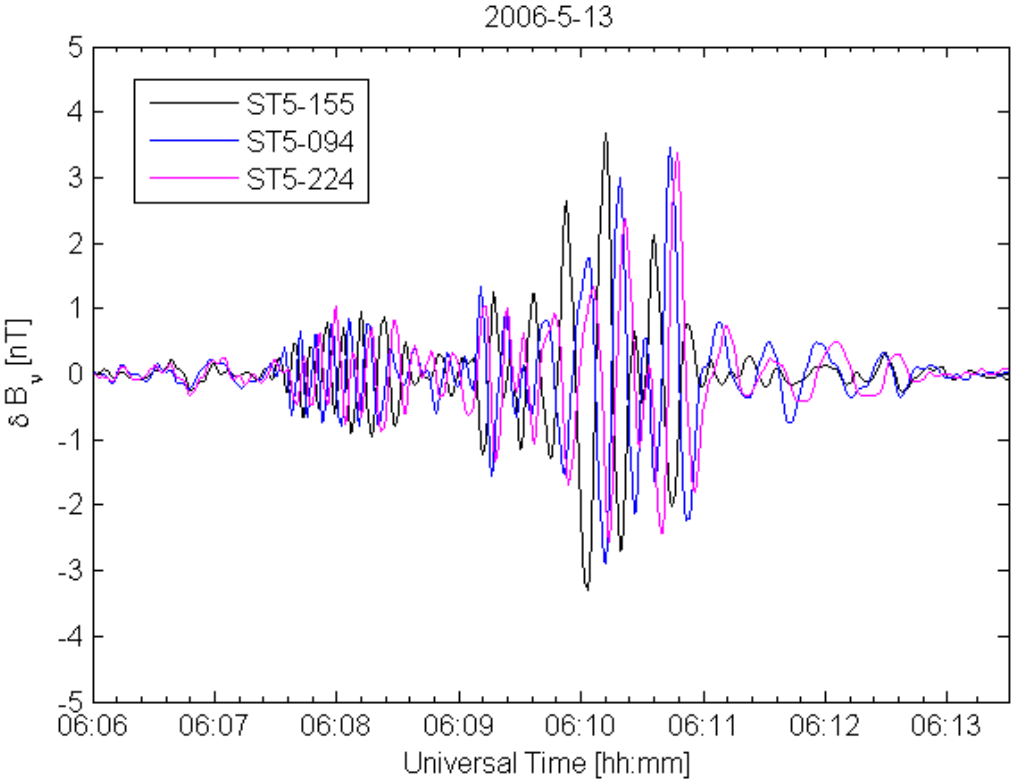
$$|m| \approx 2\pi f_{sc}\left|\frac{d\theta}{dt}\right|^{-1}$$

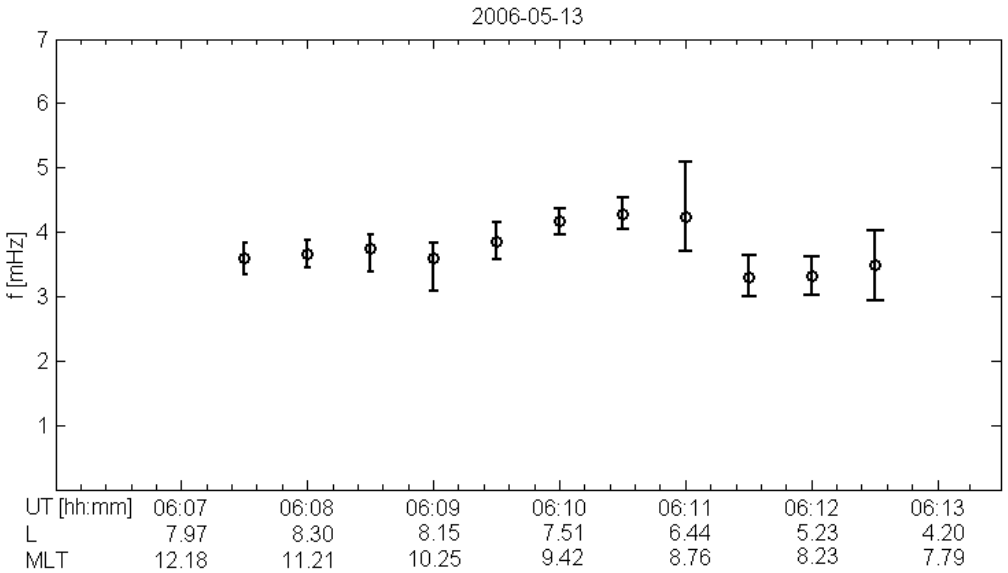
Azimuthal wavenumber:

m = 40-250 (poloidal waves)

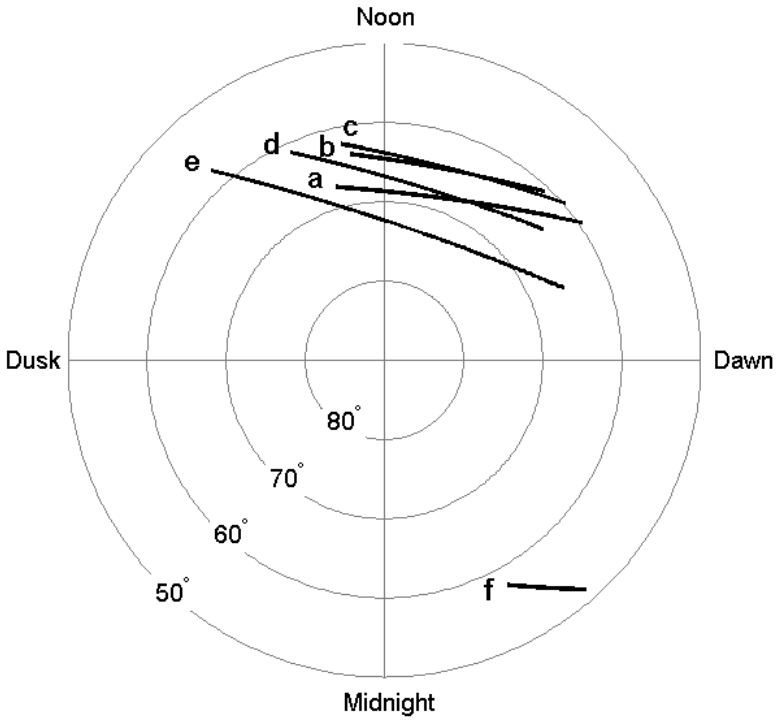
Wave Frequency in Earth Frame

$$
\begin{aligned}
B_1 &= A\cos\left(\phi_1\right), \\
B_2 &= A\cos\left(2\pi f_E t_2' + \phi_1\right), \\
B_3 &= A\cos\left(2\pi f_E t_3' + \phi_1\right).
\end{aligned}
$$

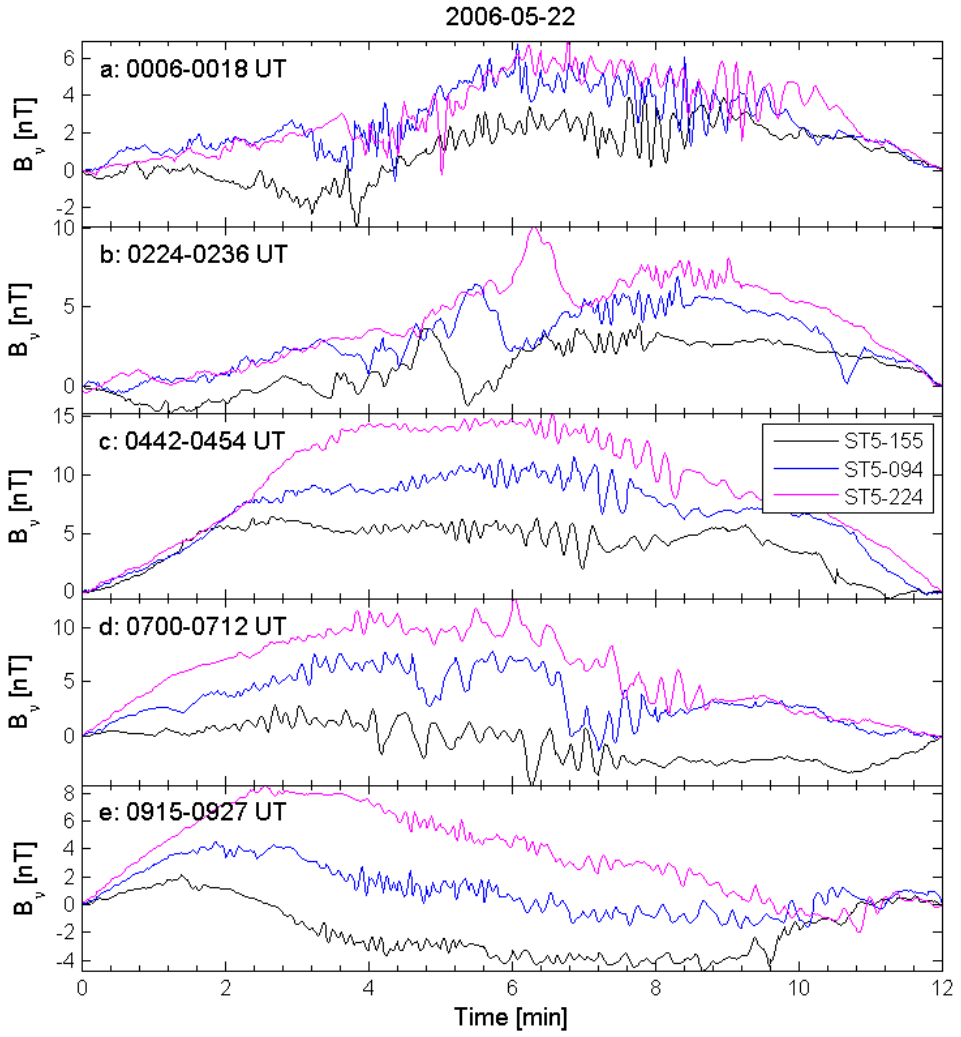




Observations during Geomagnetically Quiet Times



Chi and Le (2015)
JGR, in press.



Summary

1. Ground-based observations of “ULF meteorology”
   a) ULF waves have detailed (“meteorological”) features during active times that have not been well studied.
   b) Collaboration in ground-based magnetometer observations allows studies of ULF meteorology.
   c) Maintaining the operation of individual arrays and stations is vital.

2. Satellite observations of high-*m* poloidal waves
   a) Satellites with oblique inclination can sweep through different local times and observe Doppler-shifted poloidal waves.
   b) Unexpectedly, poloidal waves occur quite frequently during geomagnetically quiet times.

Nightside Observations of Poloidal Waves by ST-5