Investigation of ULF wave signatures which may affect JORN operations

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Background

Ultra-low frequency (~1 mHz – 1 Hz) plasma waves are ubiquitous throughout the magnetosphere and at the ionosphere, where the wave electric fields drive horizontal and vertical motions of the plasma. These can be detected by HF OTH radars, which provide greater spatial coverage than ground magnetometer arrays. The ground scatter radar mode is particularly sensitive to wave-driven vertical oscillations in the ionosphere. Furthermore, waves with small spatial scale sizes are strongly attenuated at the ground but are readily detected with HF radars.

ULF waves are generated by a variety of mechanisms, including the following.

(i) Resonances of geomagnetic field lines, producing latitude dependent frequency and phase signatures. The field lines are anchored in the ionosphere and therefore field line resonances (FLRs) have largest amplitude at local daytime, when the high ionospheric conductivity provides a high reflection coefficient. However, they are mostly observed by HF radars at local night, presumably due to propagation effects. FLR signatures have been widely reported in high latitude SuperDARN radar data [e.g. Fenrich et al., 1995] but not yet at lower latitudes.

(ii) Interactions with bouncing and drifting trapped magnetospheric electrons and ions can amplify ULF waves and energise the particles. This is an important space weather phenomenon and is subject to intense worldwide research efforts. The particles are associated with magnetic storms or substorms and the ULF waves have very small-scale sizes, therefore being heavily attenuated (and often absent) at the ground. HF radars detect a rich spectrum of these waves in the ionosphere, usually moving westward or eastward at particle drift speeds [e.g. James et al., 2016]. However, the waves are not expected at low latitudes except under extreme conditions.

(iii) Discrete frequency waves associated with magnetospheric cavity modes or driven by solar wind pressure oscillations. Waves often near 2 mHz frequency are observed on the ground at all local times and all latitudes, but their cause is still unclear and controversial. They have been extensively studied using high latitude SuperDARN radars [e.g. Walker et al., 1992] and are also prominent in mid-latitude TIGER data [Norouzi-Sedeh et al., 2015]. Magnetometer studies have shown these waves appear across Australia [Ziesolleck and Chamalaun, 1993] and are amplified near the equator [Trivedi et al., 1997] but there have been no studies with low-latitude HF radars.

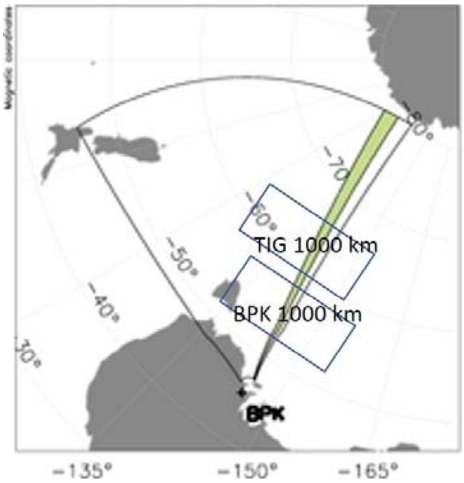
(iv) A complex variety of irregular waves accompany magnetic storms and substorms. In particular, Pi2 type signals are a signature of substorm onset and seem to be associated with different generation mechanisms at high and low latitudes. They can be seen in mid-latitude HF radar data under suitable propagation conditions [e.g. Teramoto et al., 2014], but there have been no studies at lower latitudes.

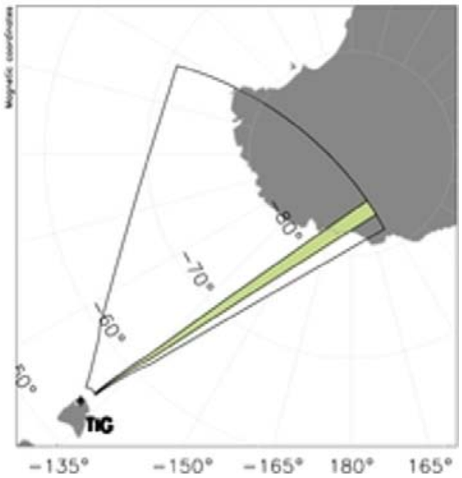
Radar operating modes for ULF wave observations

Special operating modes are often used for high resolution studies of ULF plasma waves with SuperDARN radars. Yukimatu et al. (2001) described a so-called Basyouhu mode in which one or two beams are repeated between every other beam of the normal scan, providing a 6-12 s sampling rate for those beams. The SuperDARN community runs special time operations in support of studies during satellite conjunctions (e.g. THEMIS) which provide increased time resolution suitable for ULF wave detection. During these modes the radars return to one or more designated camping beams between each successive beam, with 8 s resolution on those beams. For the TIGER and Buckland Park radars an additional, separate ULF mode has been developed which operates during discretionary time to provide high cadence sampling of only 4 selected beams.

BPK Examples
Example 1: 9 May 2015, 11 – 22 UT

Data shown are from BPK (Adelaide) and TIG (Bruny Island), beams 1 (shown below) through to 11.





Both are Beams 1.

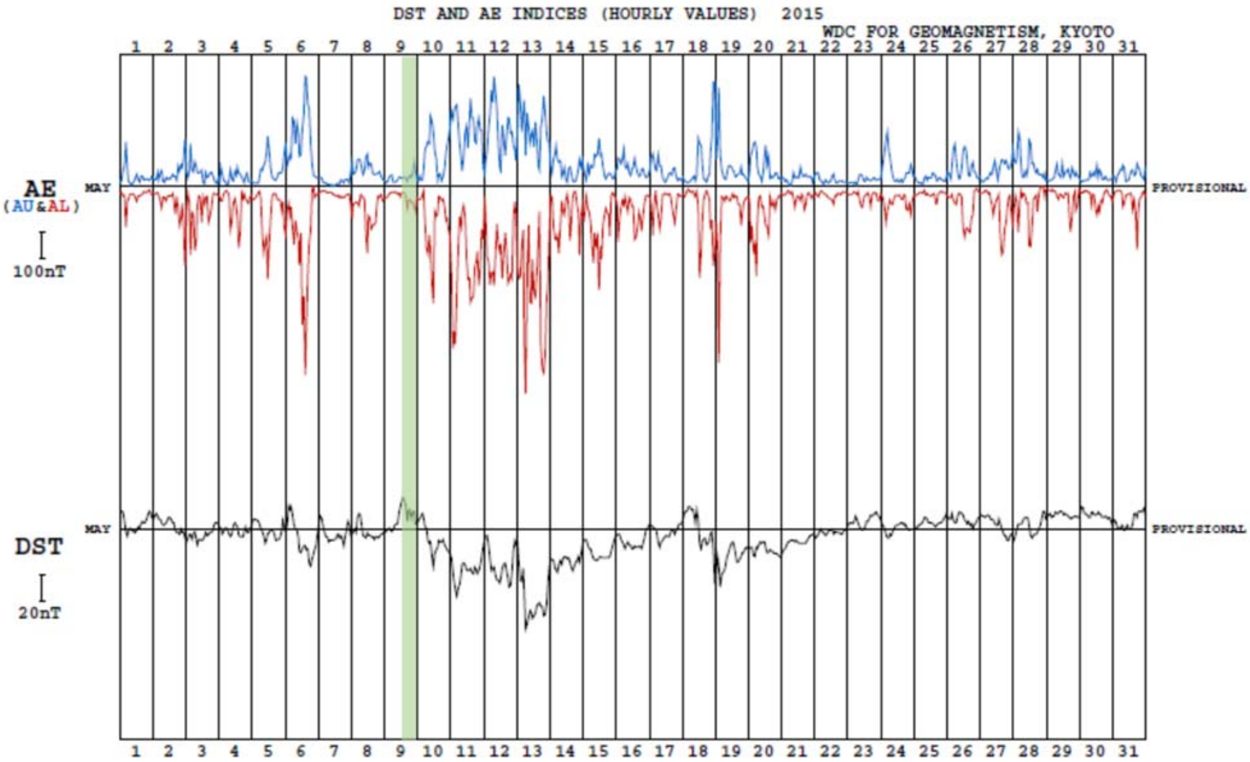
The boxes show the approximate location in the ionospheric reflection region of sea scatter at 2000 km range. Observations referred to here were obtained with sea scatter returns in the ULF wave mode, which samples 4 camping beams at high time resolution.

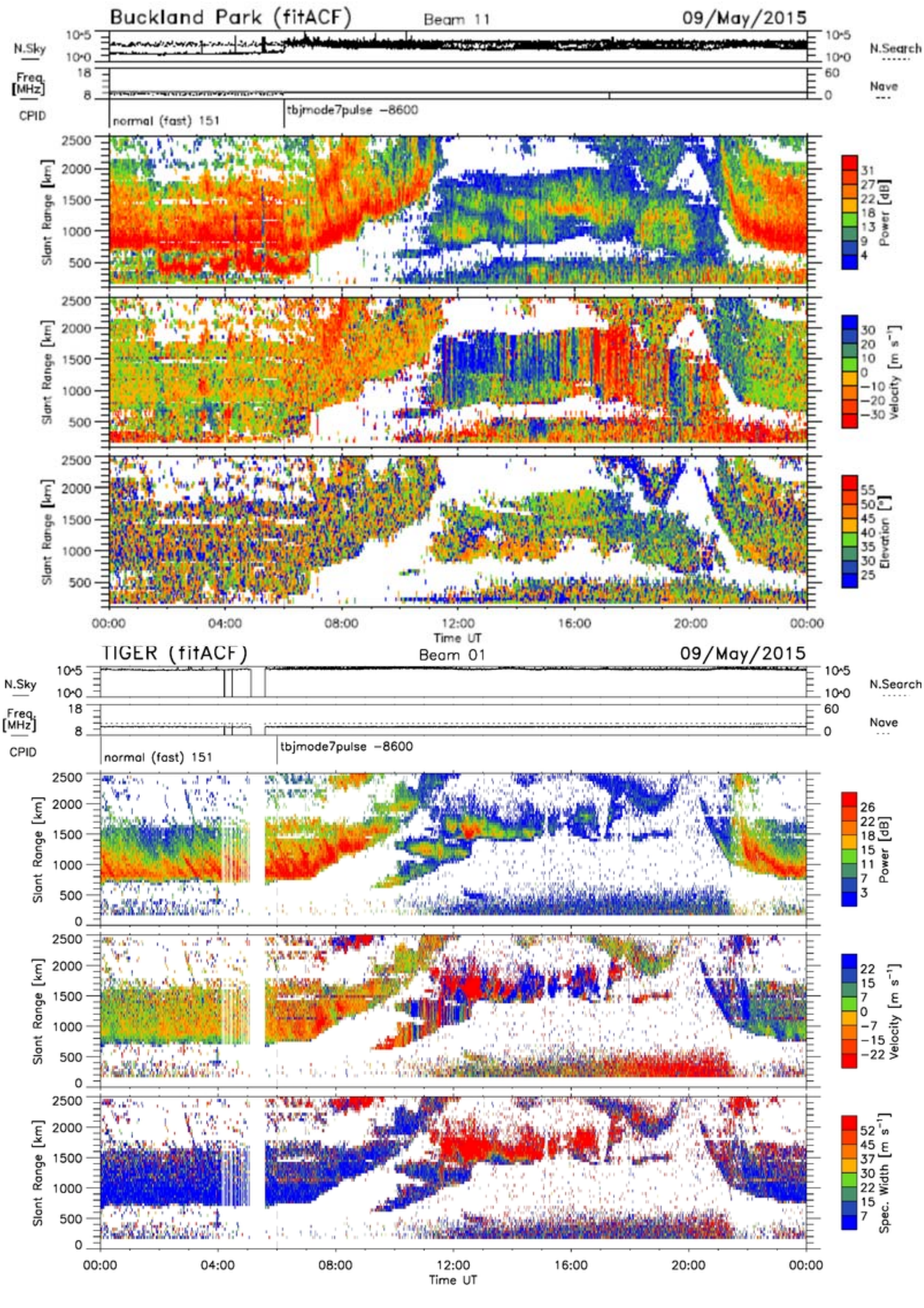
Magnetic activity was very low (Kp = 0 – 2) on the previous day but increased to around 2+ after 1000 UT on 9 May. Apart from a few hours of Kp ~ 4 on 6 May, the preceding two weeks were very quiet.

ULF wave activity is evident in BPK data from around 11 – 22 UT, across beams 1 – 11 and ranges to the ionosphere of 700 km to 2000 km in beam 11, and slightly shorter range in the more meridional beams. ULF wave activity is also present in TIG beams 1 and 11, from 1030 – 1230 UT and ranges of 800 – 1400 km. It seems likely that the waves occur over larger ranges and times but their observation is limited by propagation conditions.

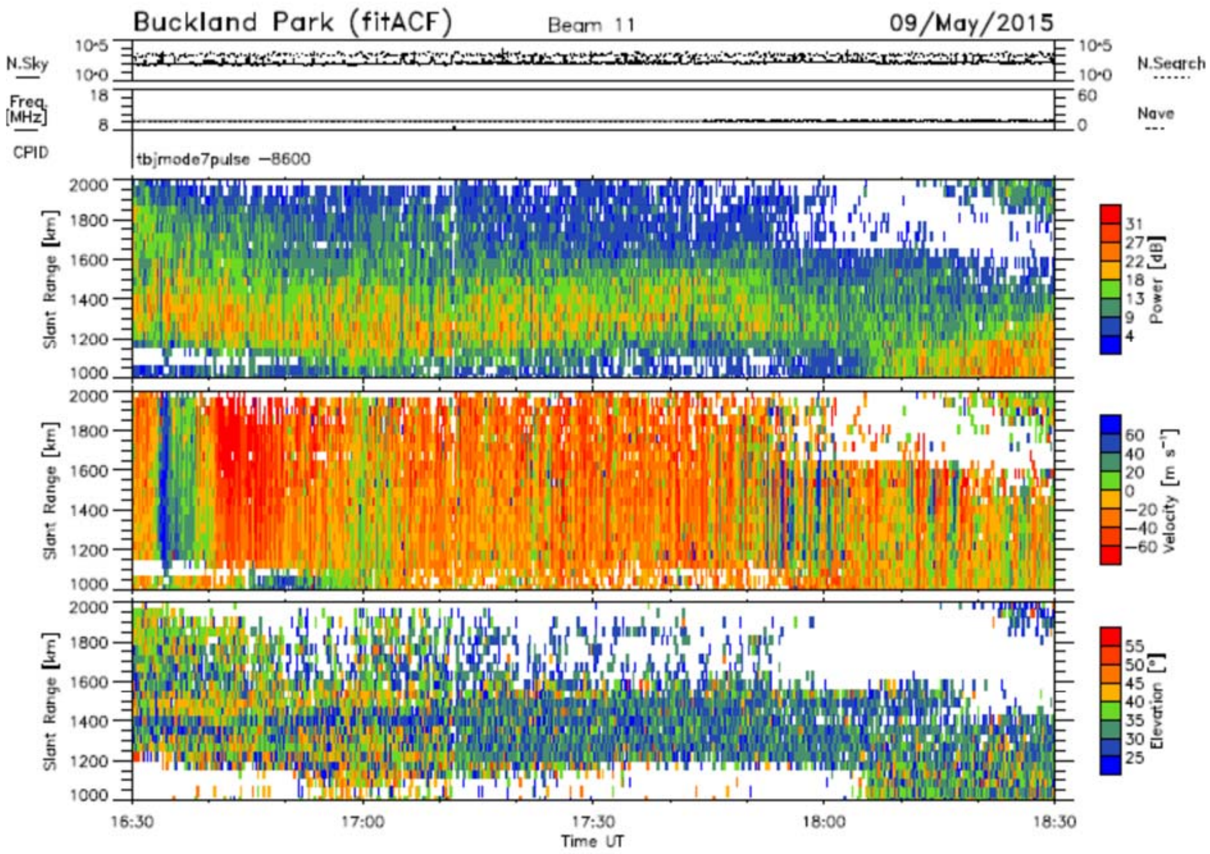
FFT spectra for selected beams (obtained using the somewhat crude on-line SuperDARN routines) show wave activity before 16 UT has frequency mostly around 4 mHz across a range of times and ranges. Higher frequencies, including possible harmonics, are present at later times in BPK.

This example clearly shows that the TIG and BPK radars can detect ULF wave signatures across a span of ranges. The cause of the wave activity seen in this example is not clear. Such sustained activity at nearly constant frequency is unusual in ground magnetometer data. The waves are unlikely to be field line resonances or generated by wave-particle interactions. They appear to be an enigmatic phenomenon of near-constant frequency signals across many hours of local (night) time. Detailed analysis would involve determining azimuthal phase speeds, and hence wave number, and comparison with ground magnetometer array data.

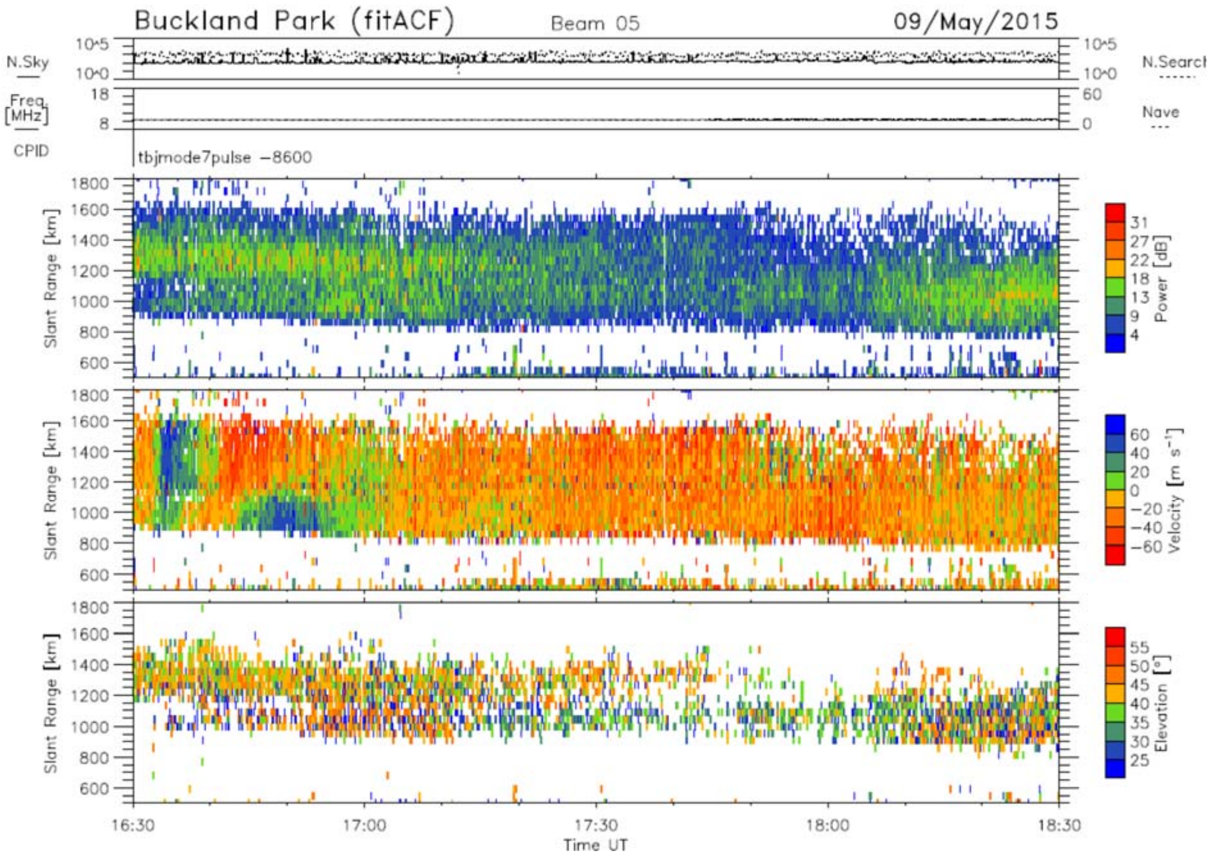

DST AND AE INDICES (HOURLY VALUES) 2015
WDC FOR GEOMAGNETISM, KYOTO
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
AE
(AU&AL)
100nT
MAY
PROVISIONAL
DST
20nT
MAY
PROVISIONAL
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31



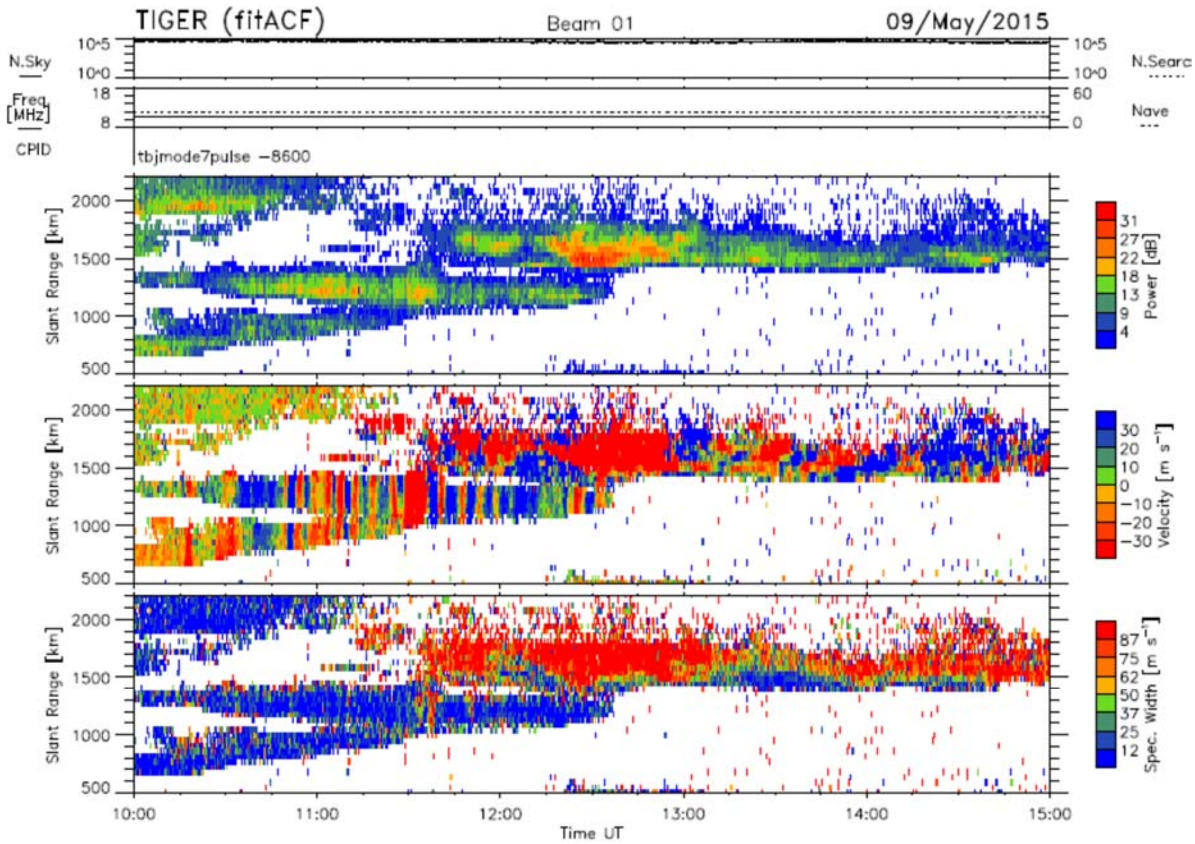
Buckland Park (fitACF)
Beam 11
09/May/2015
N.Sky
N.Search
Freq. [MHz]
Nave
CPID
normal (fast) 151
tbjmode7pulse −8600
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
Elevation [°]
Time UT
TIGER (fitACF)
Beam 01
09/May/2015
Spec. Width [m s⁻¹]

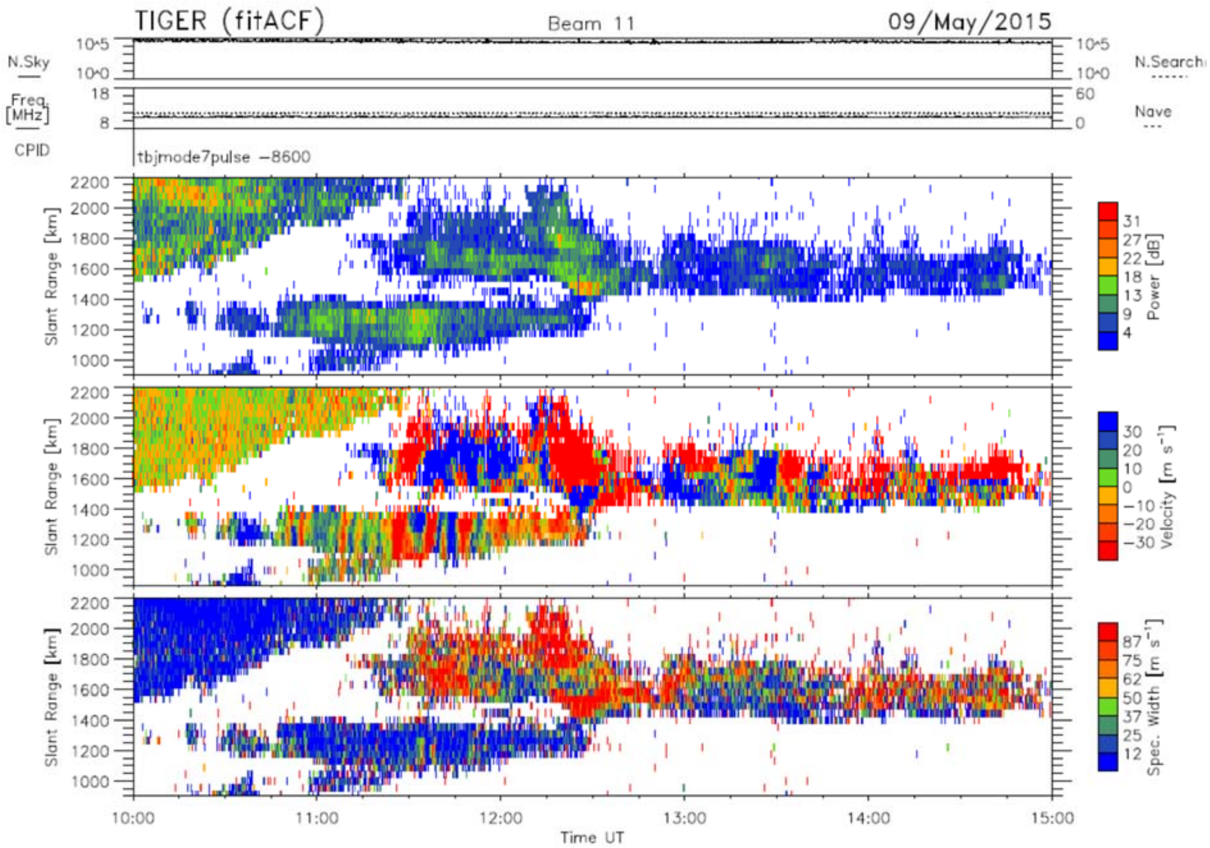


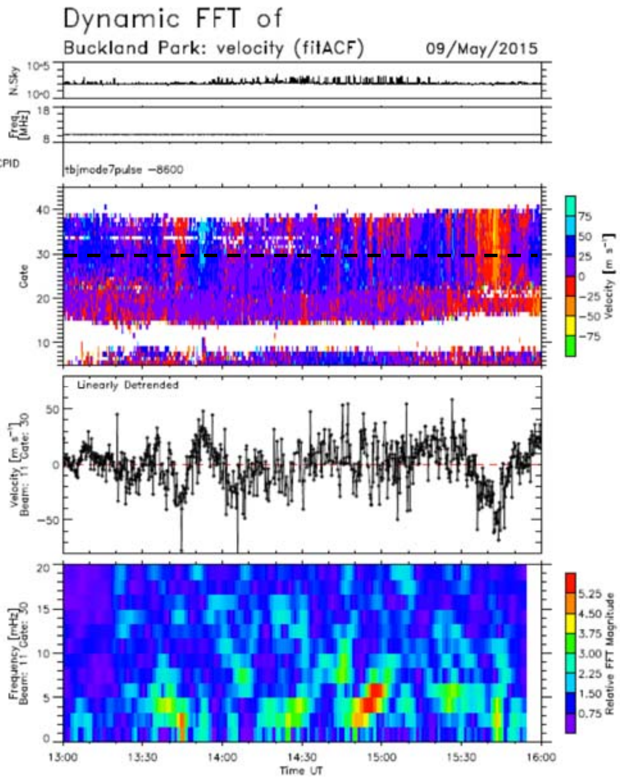
Buckland Park (fitACF)
Beam 11
09/May/2015
N.Sky
N.Search
Freq [MHz]
Nave
CPID
tbjmode7pulse −8600
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
Elevation [°]
Time UT



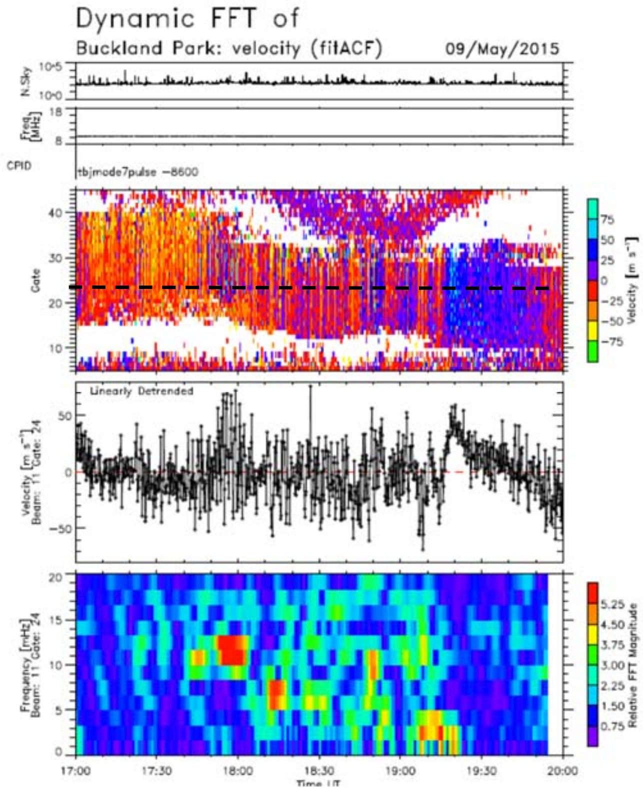
Buckland Park (fitACF)
Beam 05
09/May/2015
N.Sky
N.Search
Freq [MHz]
Nave
CPID
tbjmode7pulse −8600
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
Elevation [°]
Time UT


TIGER (fitACF)
Beam 01
09/May/2015
N.Sky
N.Searc
Freq [MHz]
Nave
CPID
tbjmode7pulse −8600
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
Spec. Width [m s⁻¹]
Time UT

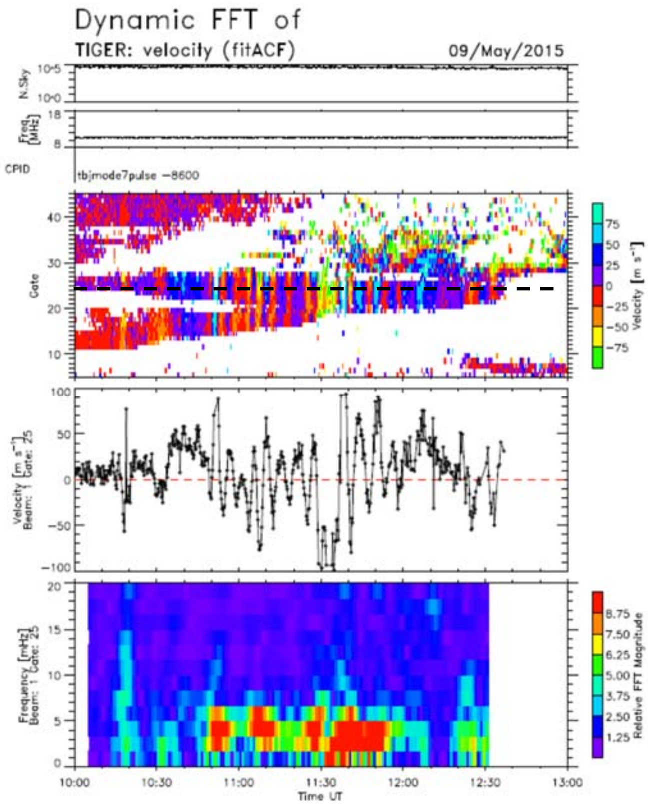

TIGER (fitACF)
Beam 11
09/May/2015
N.Sky
N.Search
Freq [MHz]
Nave
CPID
tbjmode7pulse −8600
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
Spec. Width [m s⁻¹]
Time UT



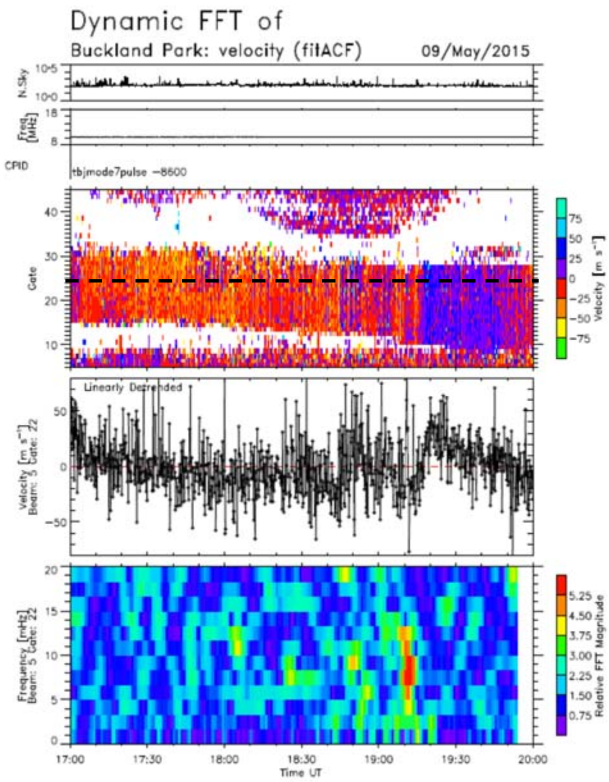
FFT for BPK 13 – 16 UT beam 11, gate 30



FFT for BPK 17 – 20 UT, beam 11, gate 24 (above) and beam 5, gate 22 (below)

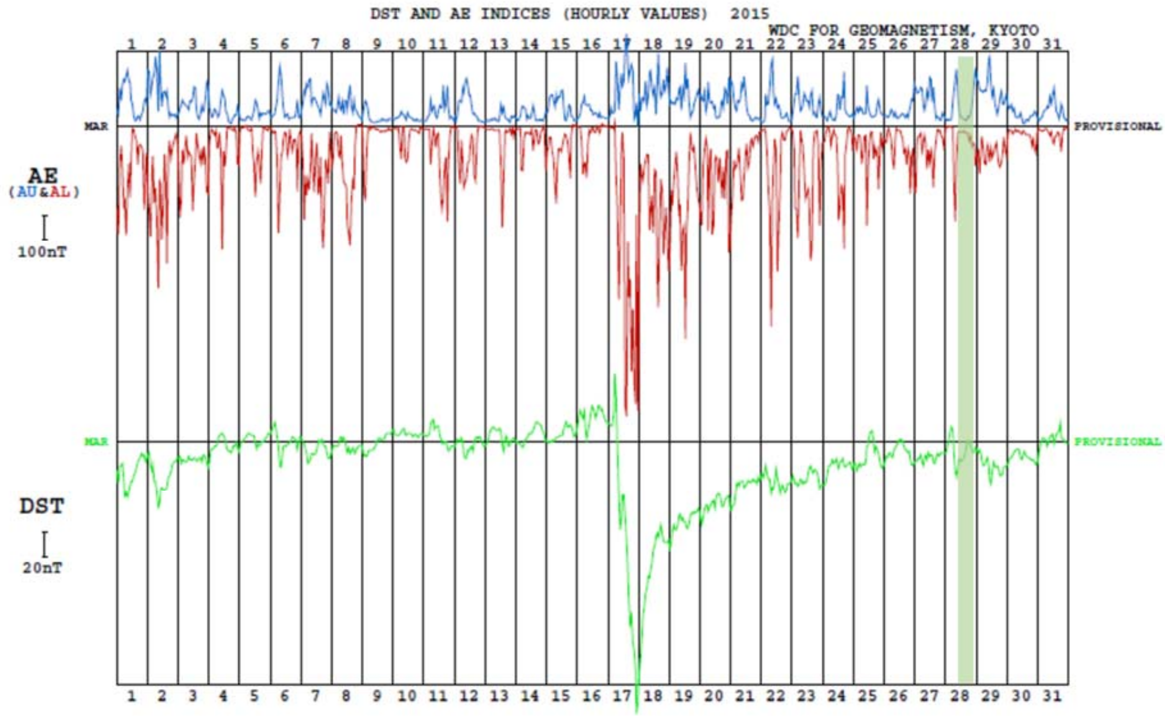


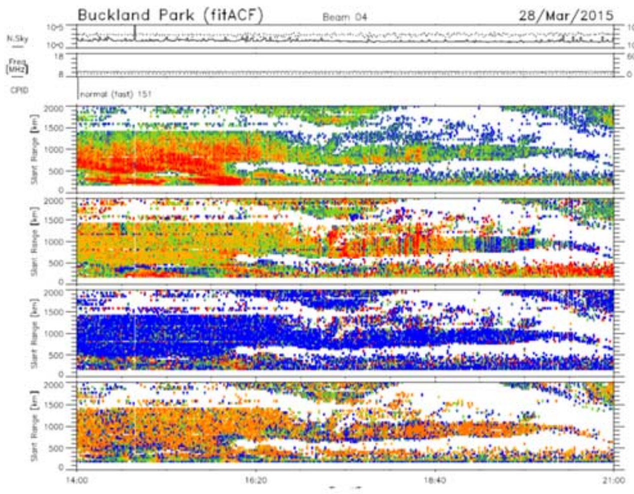
FFT for TIG 10 – 13 UT beam 1, gate 25

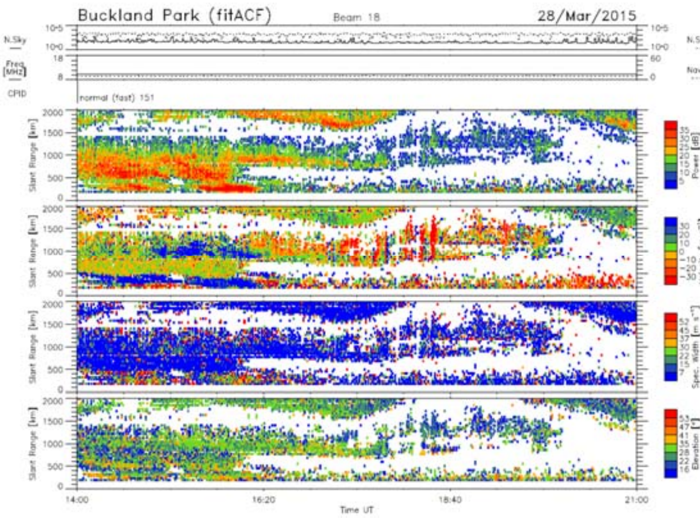


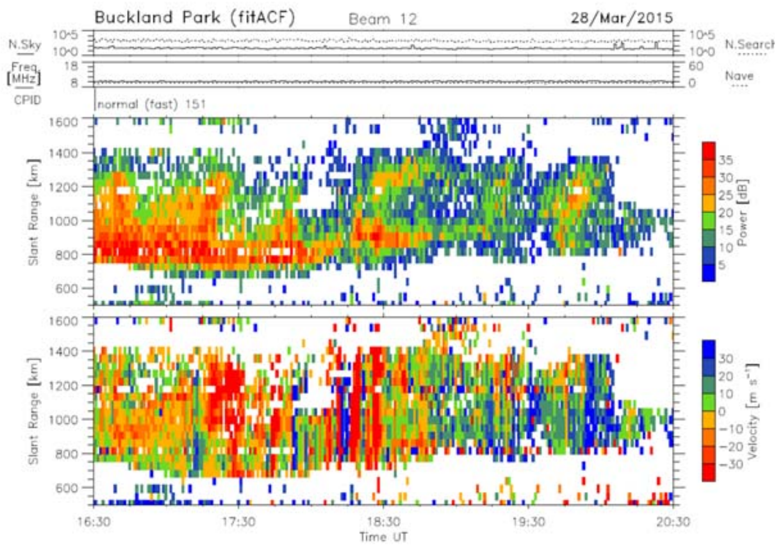
Example 2: 28 March 2015, Kp ~ 2, 16 – 19 UT

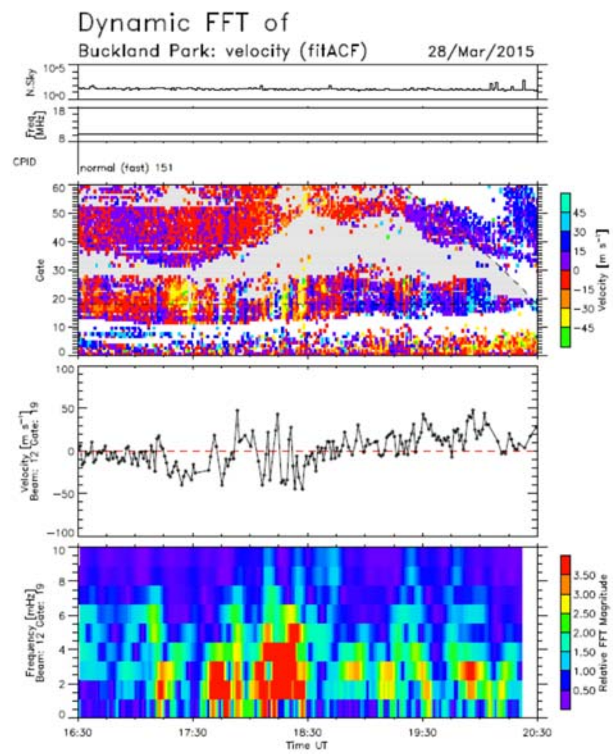
This is likely an example of a substorm associated-Pi2 event. Associated ionospheric signatures are expected globally but here are seen in BPK data sea scatter at ranges of 800 – 1200 km.




Buckland Park (fitACF)
Beam 04
28/Mar/2015
N.Sky
N.Search
Freq [MHz]
Nave
CPID
normal (fast) 151
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
Spec. Width [m s⁻¹]
Elevation [°]
14:00
16:20
18:40
21:00

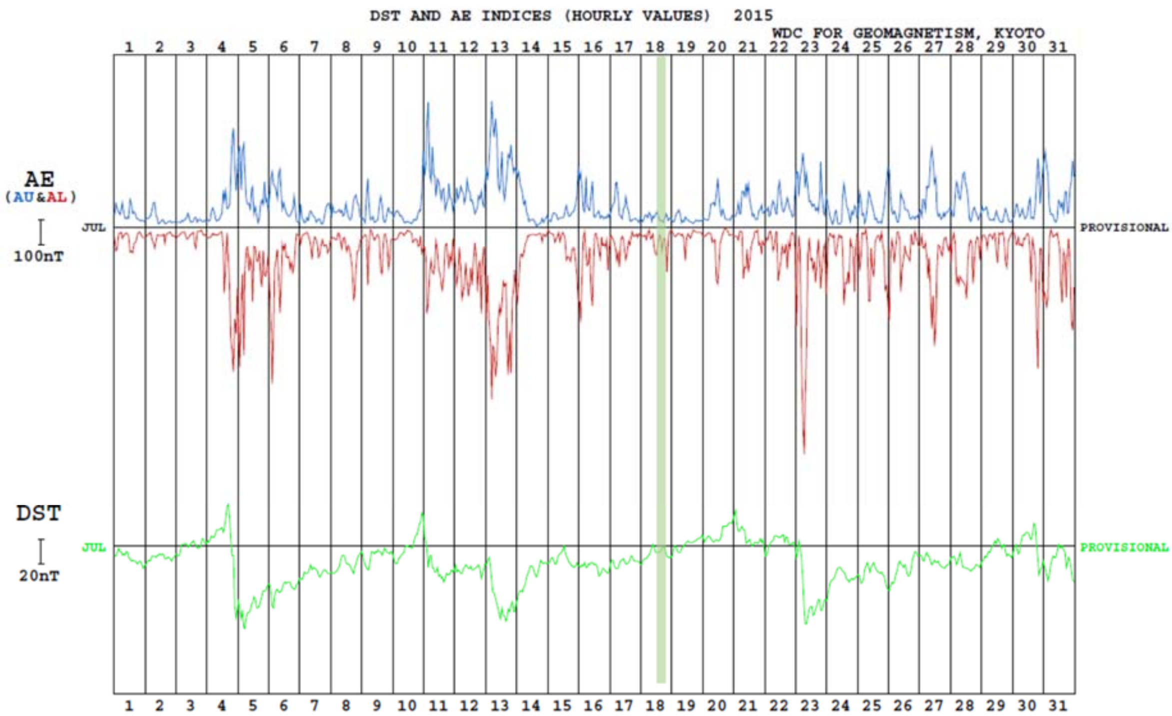

Buckland Park (fitACF)
Beam 18
28/Mar/2015
N.Sky
N.Search
Freq [MHz]
Nave
CPID
normal (fast) 151
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
Spec. Width [m s⁻¹]
Elevation [°]
14:00
16:20
18:40
21:00
Time UT

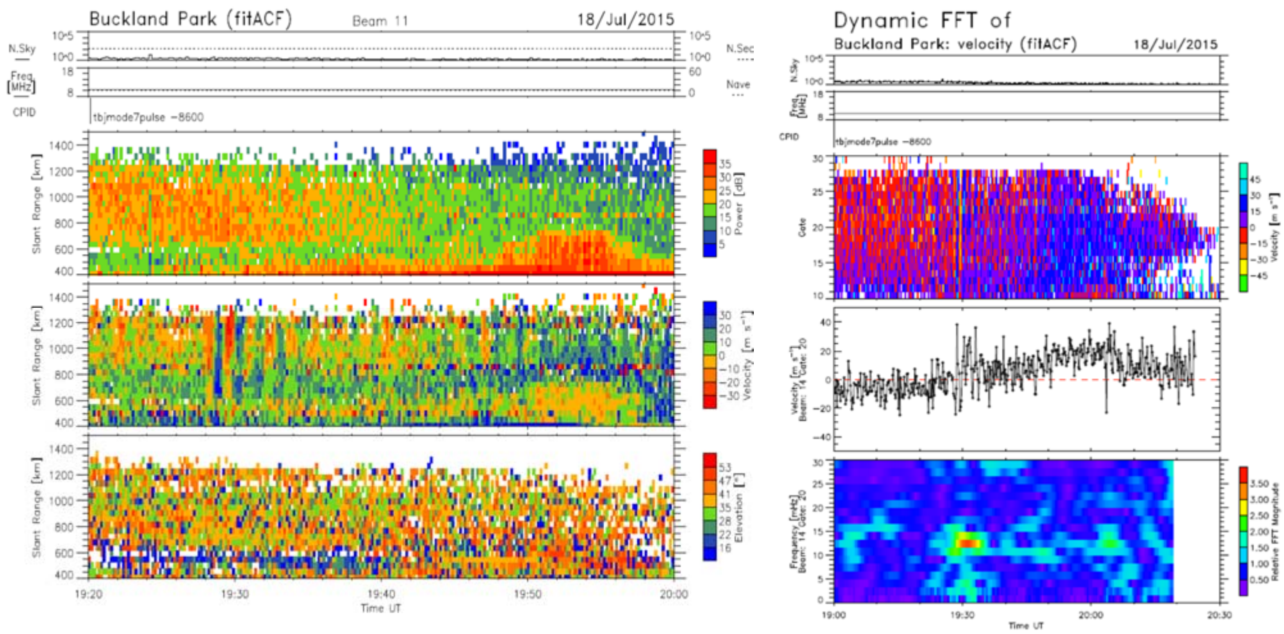

Buckland Park (fitACF)
Beam 12
28/Mar/2015
N.Sky
N.Search
Freq [MHz]
Nave
CPID
normal (fast) 151
Slant Range [km]
Power [dB]
Velocity [m s⁻¹]
16:30
17:30
18:30
19:30
20:30
Time UT


Dynamic FFT of
Buckland Park: velocity (fitACF)
28/Mar/2015
N.Sky
Freq [MHz]
CPID
normal (fast) 151
Gate
Velocity [m s⁻¹]
Velocity [m s⁻¹] Beam: 12 Gate: 19
Frequency [mHz] Beam: 12 Gate: 19
Relative FFT Magnitude
16:30
17:30
18:30
19:30
20:30
Time UT

Example 3: 18 July 2015, 19 - 2030 UT, Kp = 0 - 1 2,

This example occurs under very quiet conditions. Waves near 14 mHz are seen over ~ 1 hour and 600 – 1200 km range to the ground in BPK data across all beams. The cause of these ULF waves is not clear but they may be field line resonances.





BPK range-time plot (left), beam 14 1920 – 2000 UT, showing Doppler oscillations over ±40 m/s, and (right) FFT over 1900 – 2030 beam 14, range gate 20 (~ 500 km SE of BPK) with oscillations around 13 mHz.

JORN Related Studies

Are such ULF-wave driven oscillations relevant and important for JORN operations?

If so, issues which could be pursued include the following.

- Are ULF waves which are identified in BPK data also present in the ionosphere at lower latitudes?
- What are the propagation characteristics and causes of the waves seen?
- Using coupled MHD-ionosphere models, can we reproduce the ionospheric signatures observed by radars? Hence, can we develop an understanding of when to expect such wave features and their can we predict their ionospheric signature?

References:

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