Monitoring Irregularities in the Mid-Latitude Ionosphere Using HF Radars

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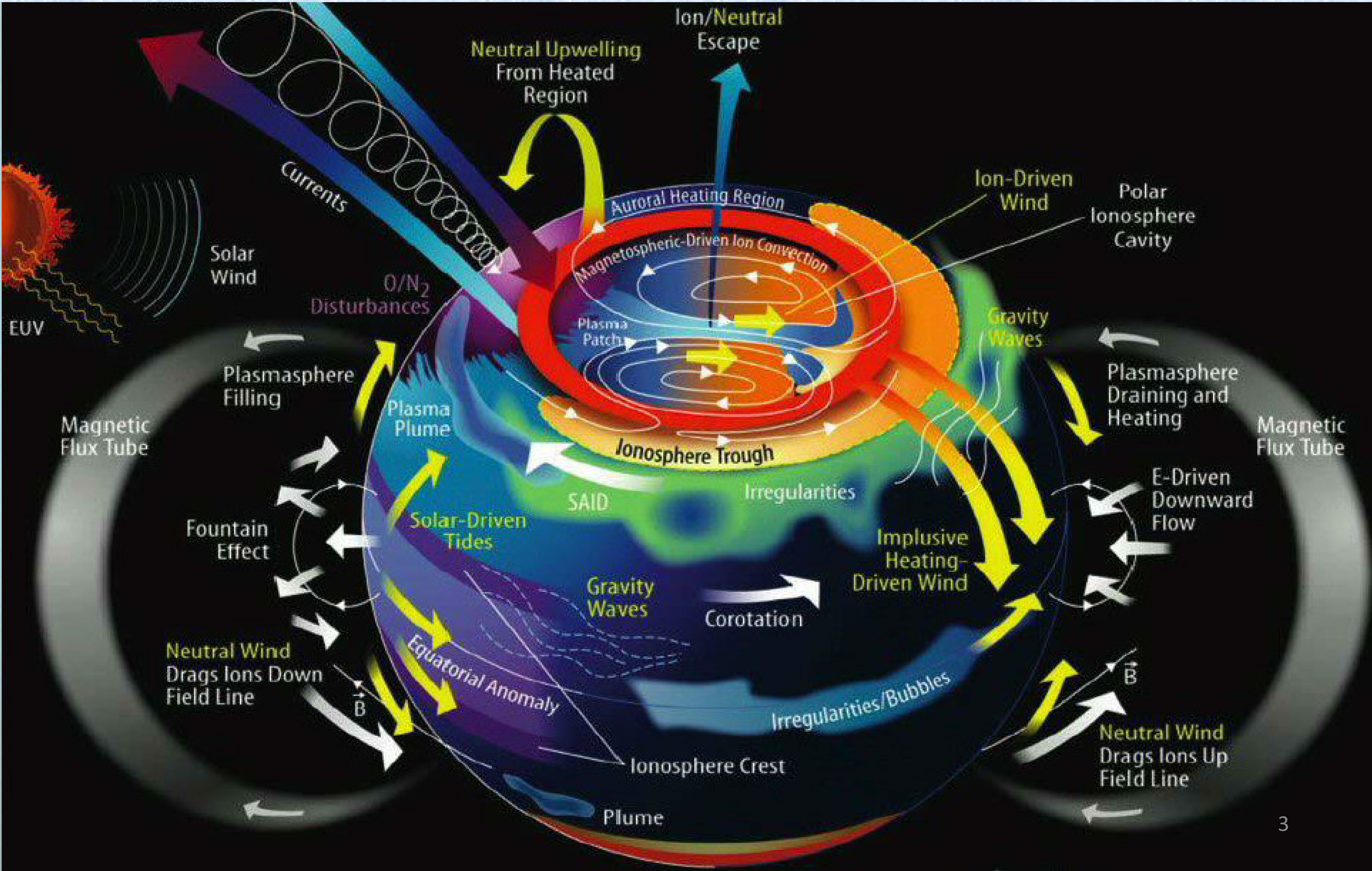
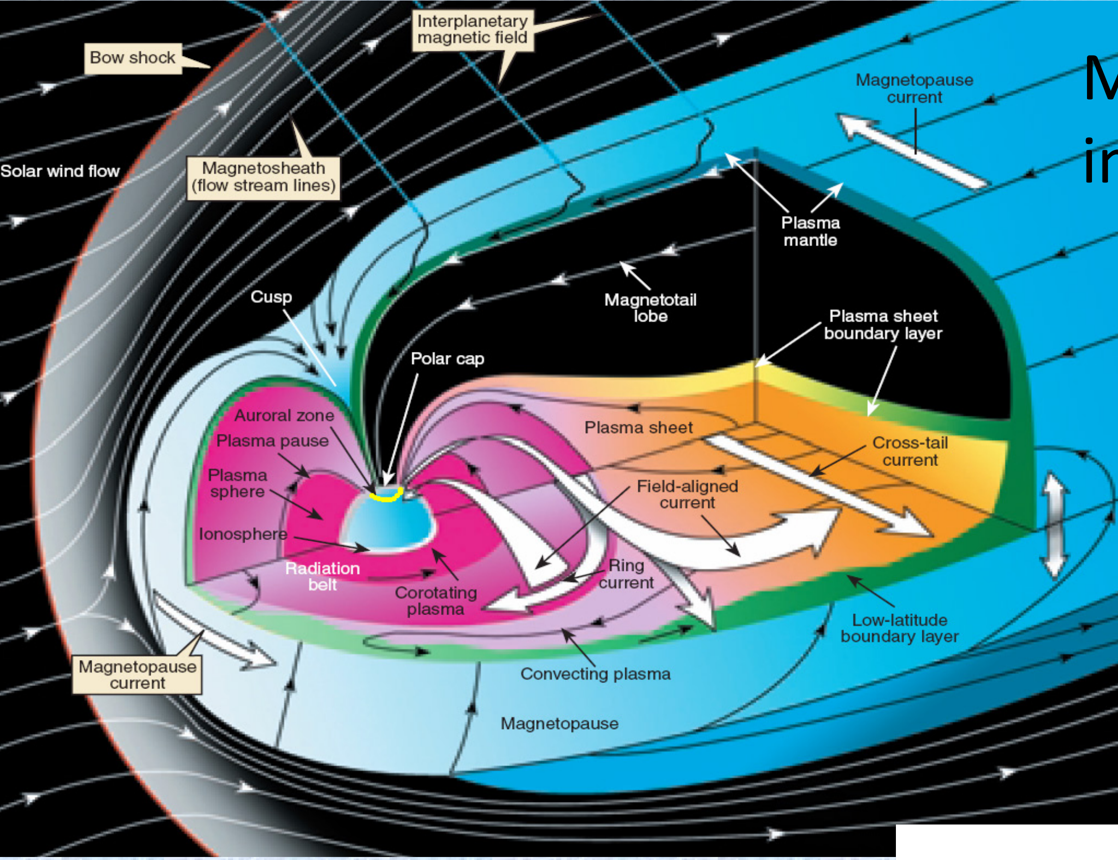
Main Points

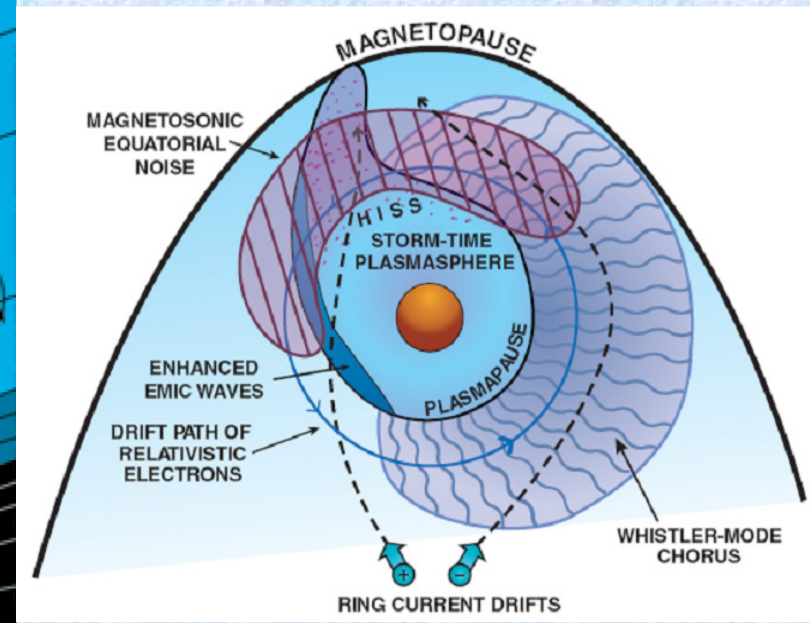
- M-P-I coupling is a key component of space weather
- Space weather effects thus occur in the ionosphere at all latitudes and impact a range of users
- An international consortium of HF over-the-horizon radars has been developed for ionospheric research
- The mid-latitude radars can examine the projection of the radiation belt and ring current to the ionosphere
- Observations show substorm-related convective flows, and wave and wave-particle events
- The observations inform models of plasma wave interaction with the ionosphere
- This is an underdeveloped area of research

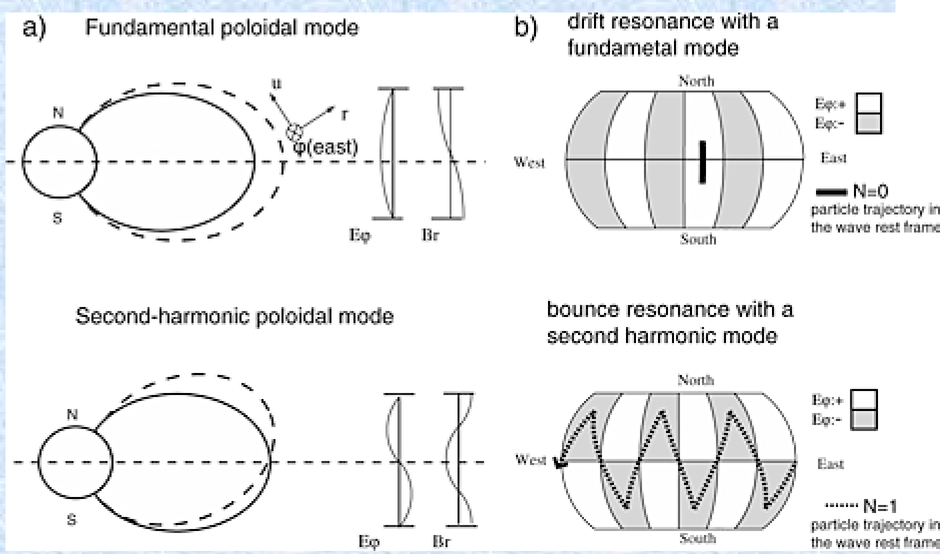
The ionosphere is dynamically linked with the magnetosphere above and the atmosphere below

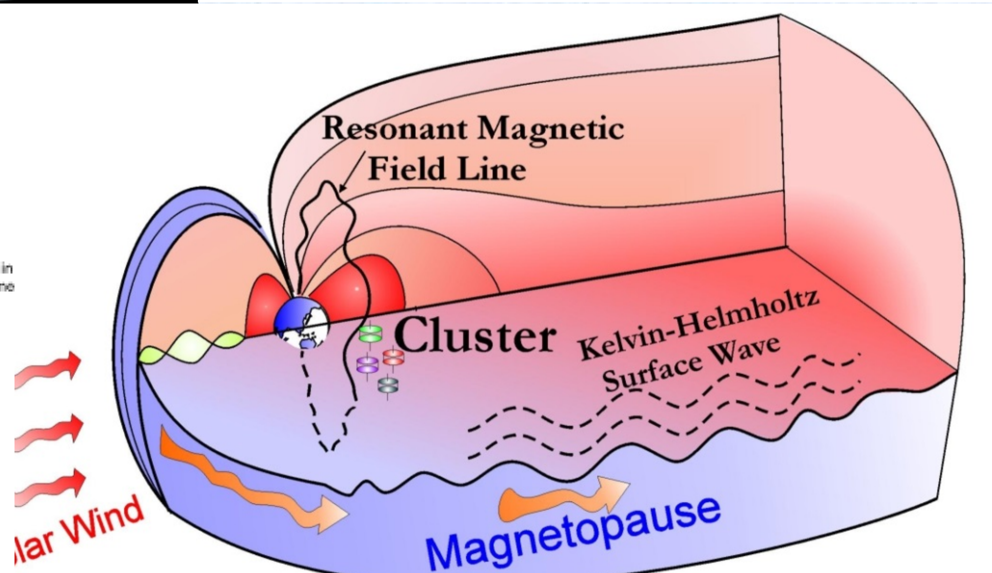


Many wave processes occur in the magnetosphere

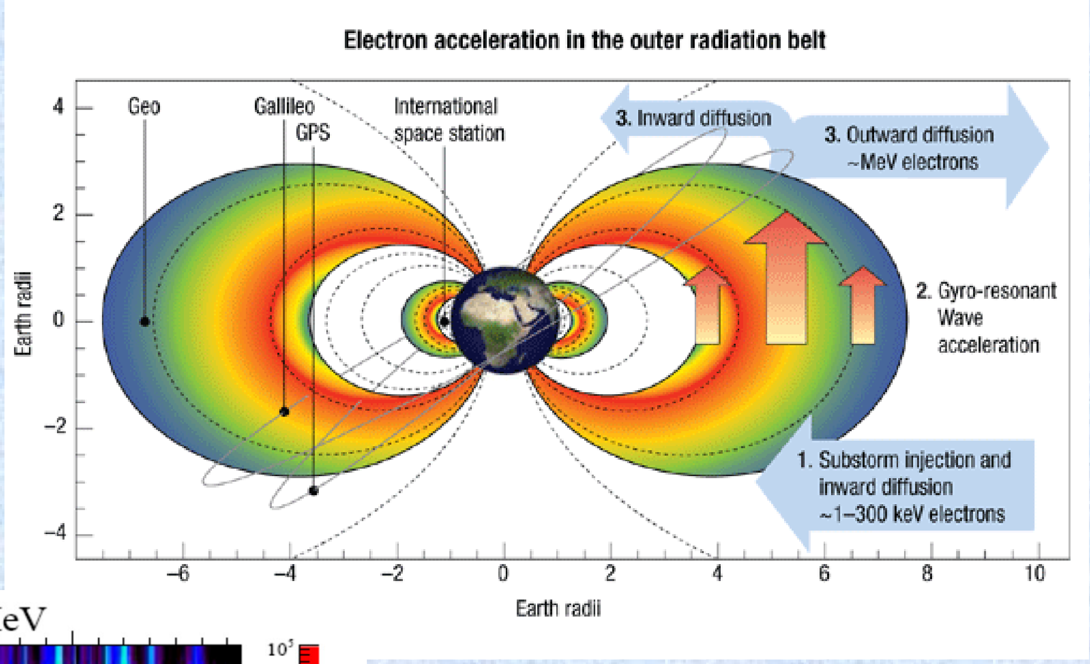


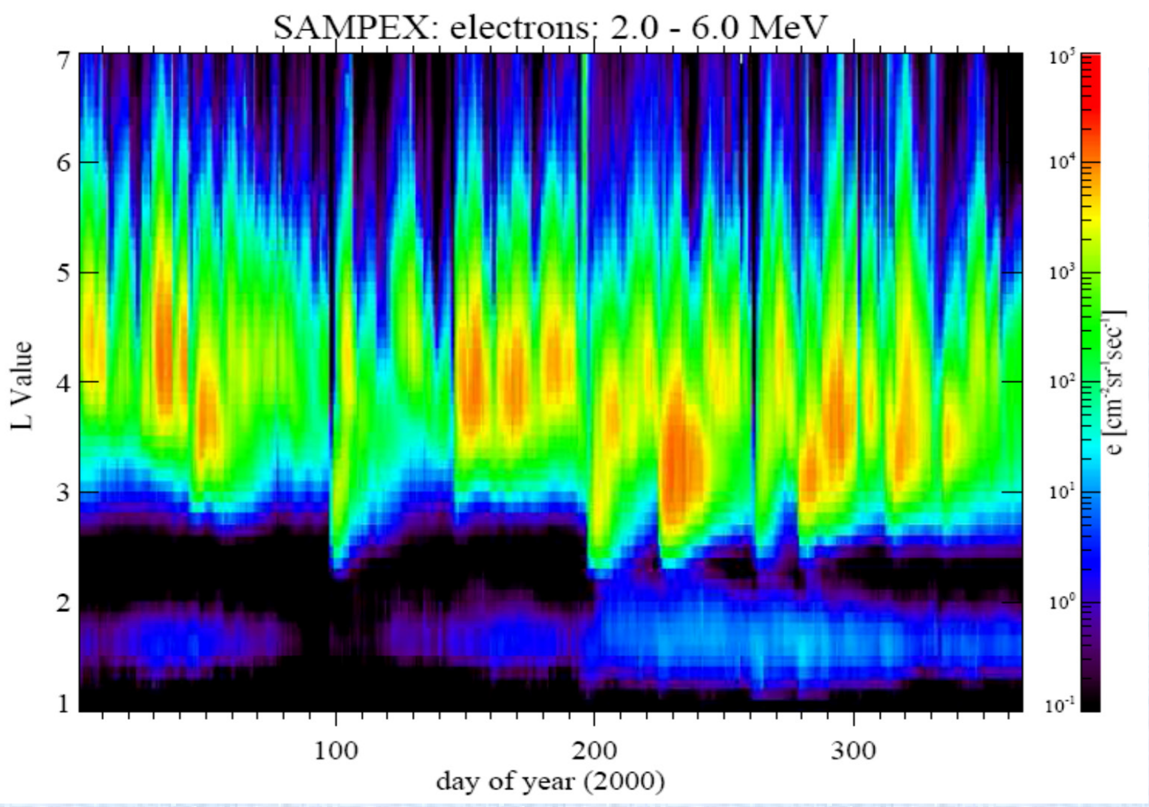






The radiation belts map to the mid-latitude ionosphere





Radiation belt energetic particle flux over a solar maximum year

Space weather effects in the ionosphere

High latitudes

Signatures of energy and momentum transfer from the solar wind, e.g. convective flows and flow bursts; storm phenomena, e.g. absorption ; scintillation, e.g. for GNSS

Middle latitudes

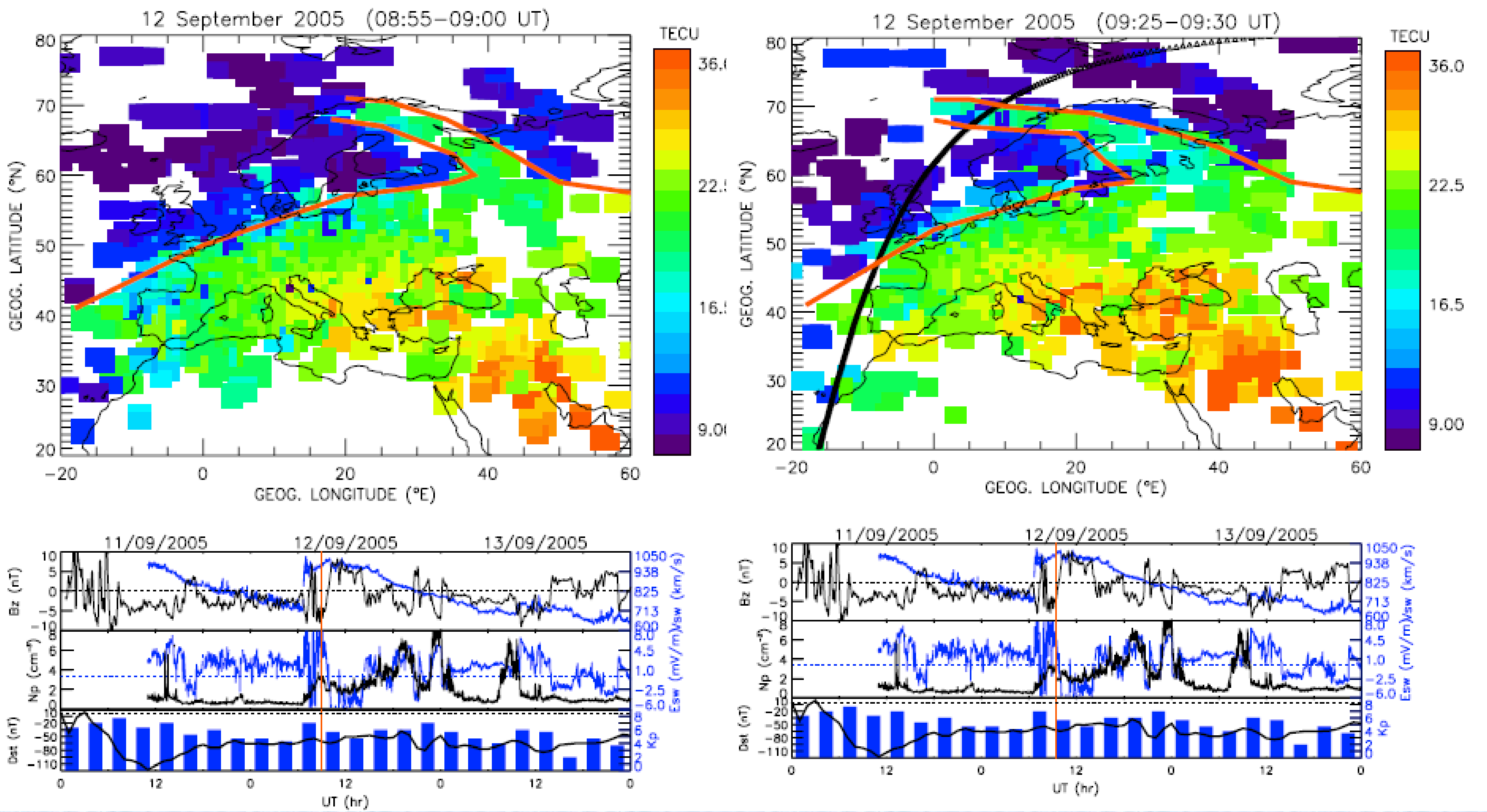
Enhanced convective flows and density structures; TIDs?; plasma wave driven density variations; substorm effects

Low latitudes

Irregularities producing scintillation, degradation of radio astronomy signals, Doppler clutter in surveillance radars

Example: plasmaspheric plumes

Plasmasphere erosion causes storm-time density gradients



Yizengaw et al., GRL, 2006. Southward turning Bz causes antisunward ExB convection in the magnetosphere morning sector.

Ionospheric signature of plasmaspheric plume

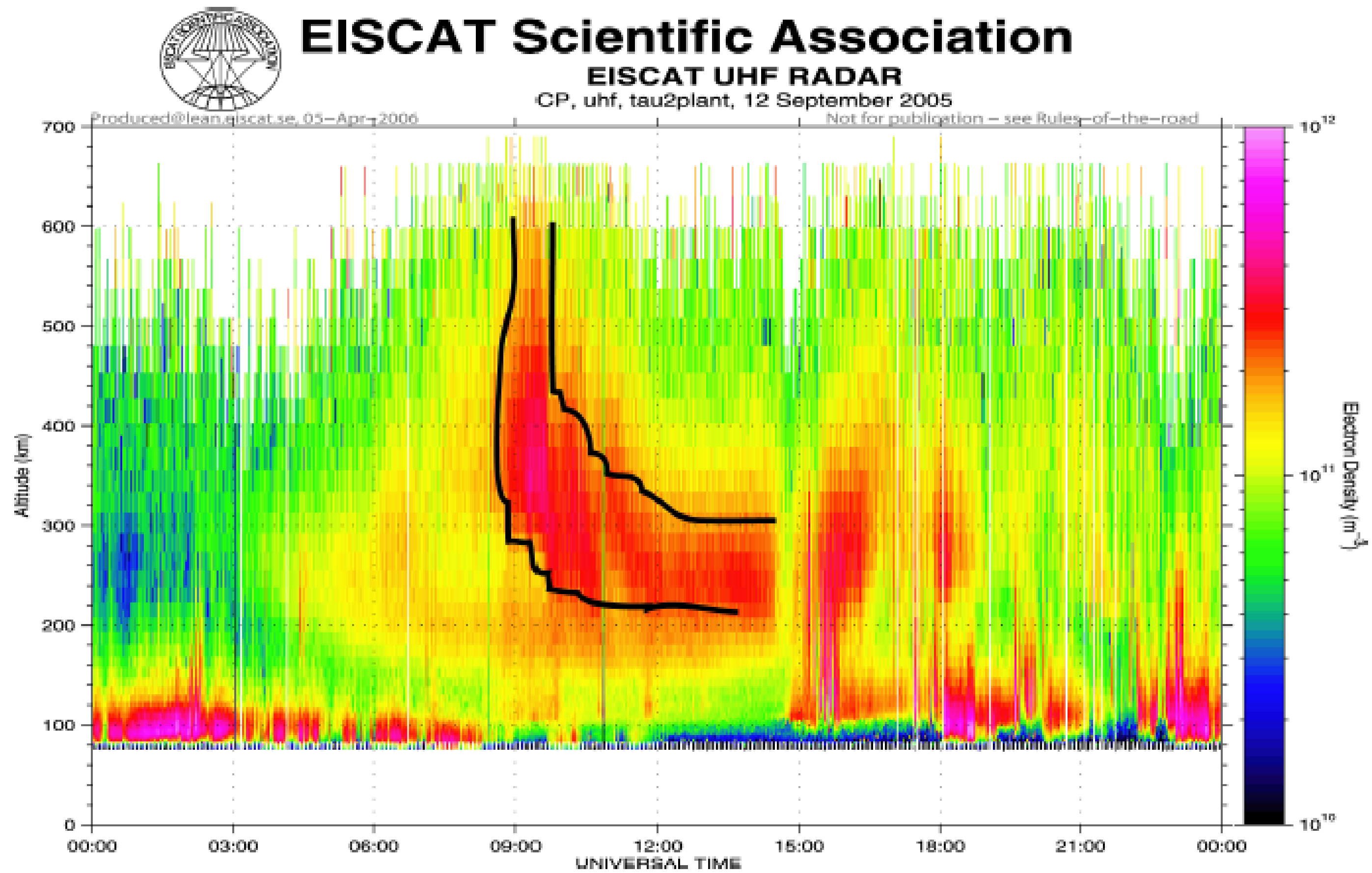
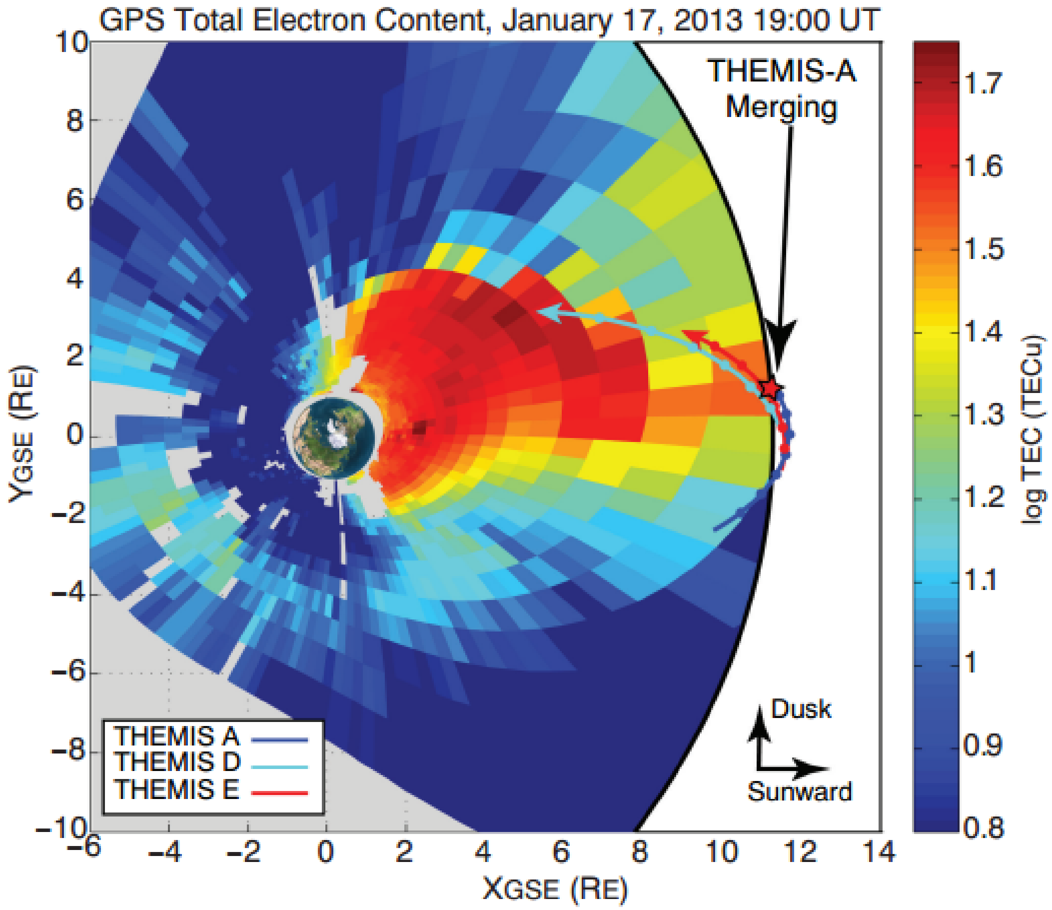


Figure 3. The 2-D maps of electron density obtained by the EISCAT radar. The curved black line illustrates the orientation of the enhanced density from the dayside to the morning sector.

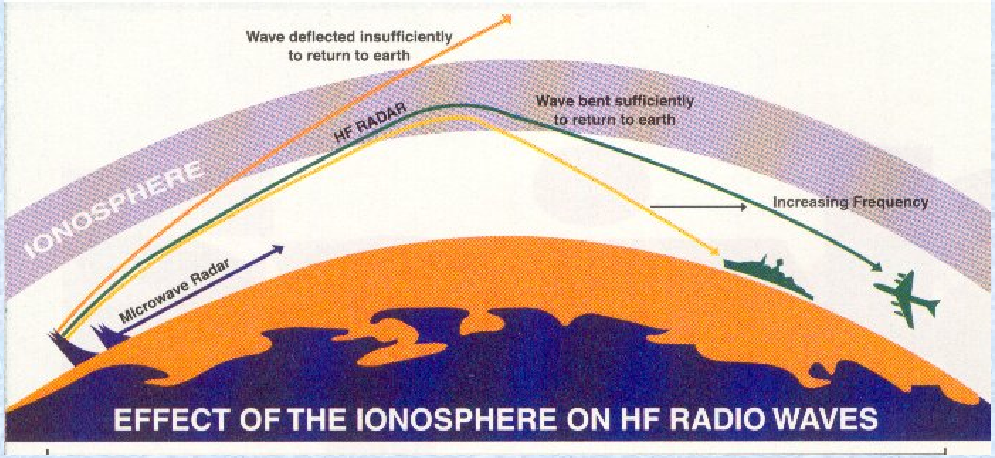
Plumes extend to the magnetopause and affect reconnection

Fig. 2. TEC measurements projected to the equatorial plane following magnetic field lines with the International Geomagnetic Reference Field (IGRF) model. The star indicates the position where the THEMIS A spacecraft crosses the magnetopause. The solid circles along the orbit are each separated by 1 hour spanning the time period from 16 to 22 UT. The black line is a modeled position of the magnetopause (*22*).

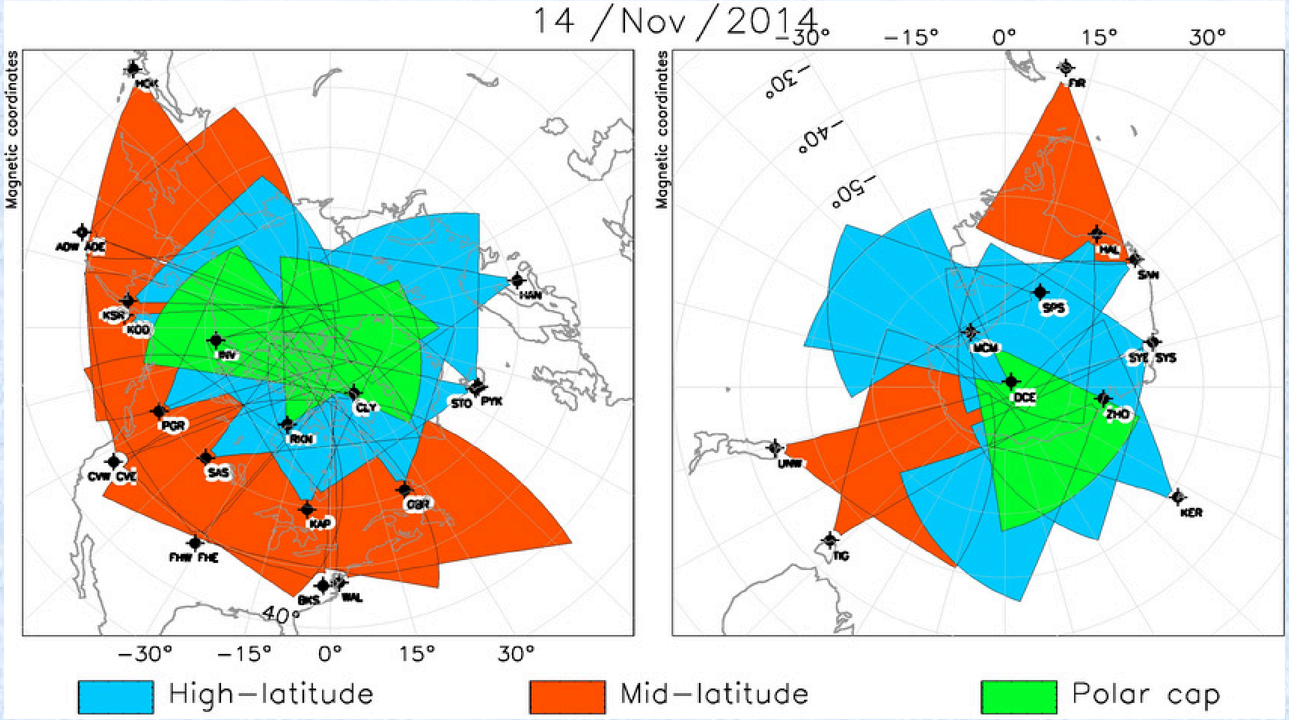
Walsh et al., Science, 2014



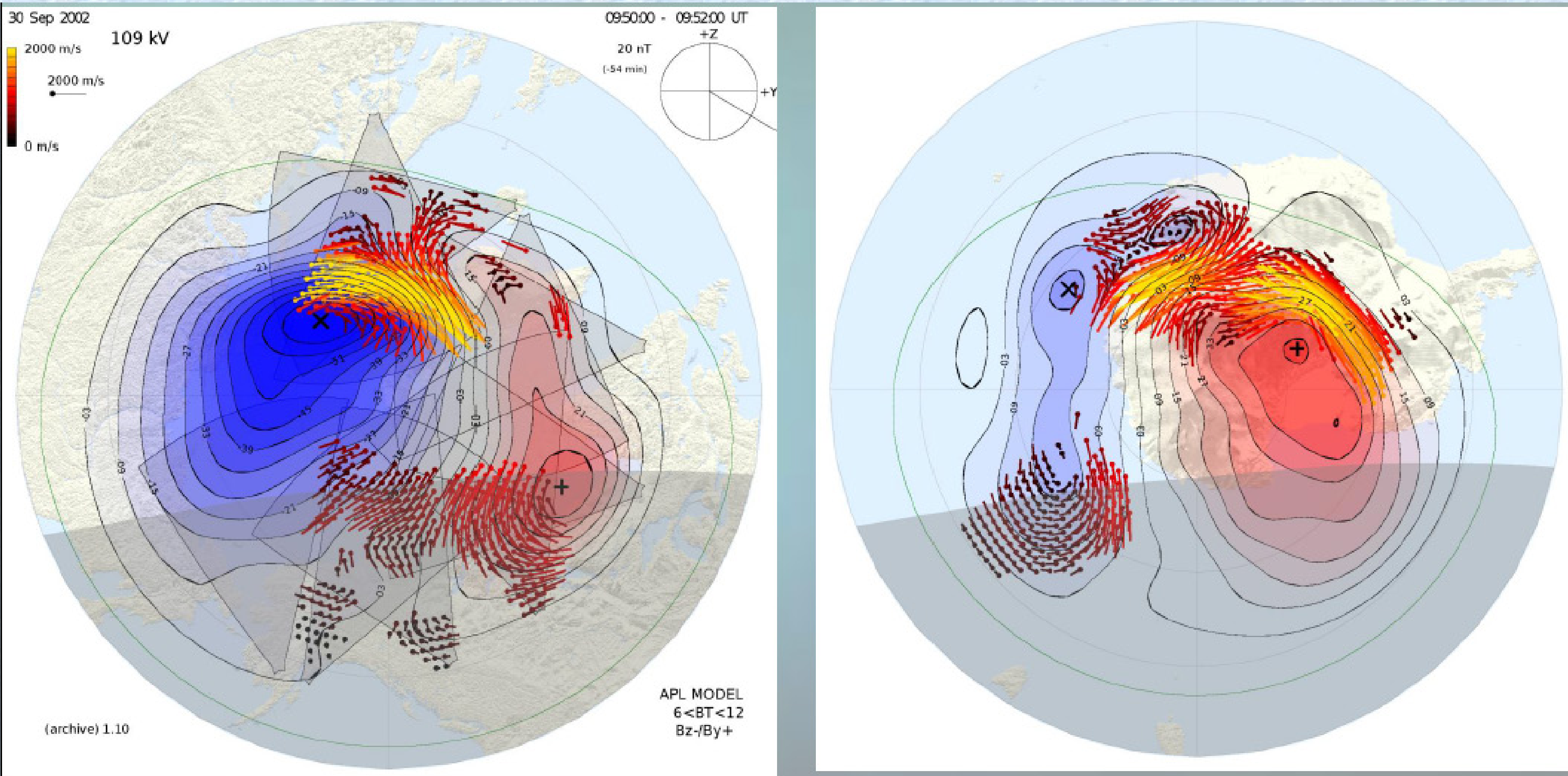
High frequency (HF) over-the-horizon radars



HF radars measure intensity and Doppler shift of backscatter from the ionosphere. SuperDARN is a network of research HF OTHRs.

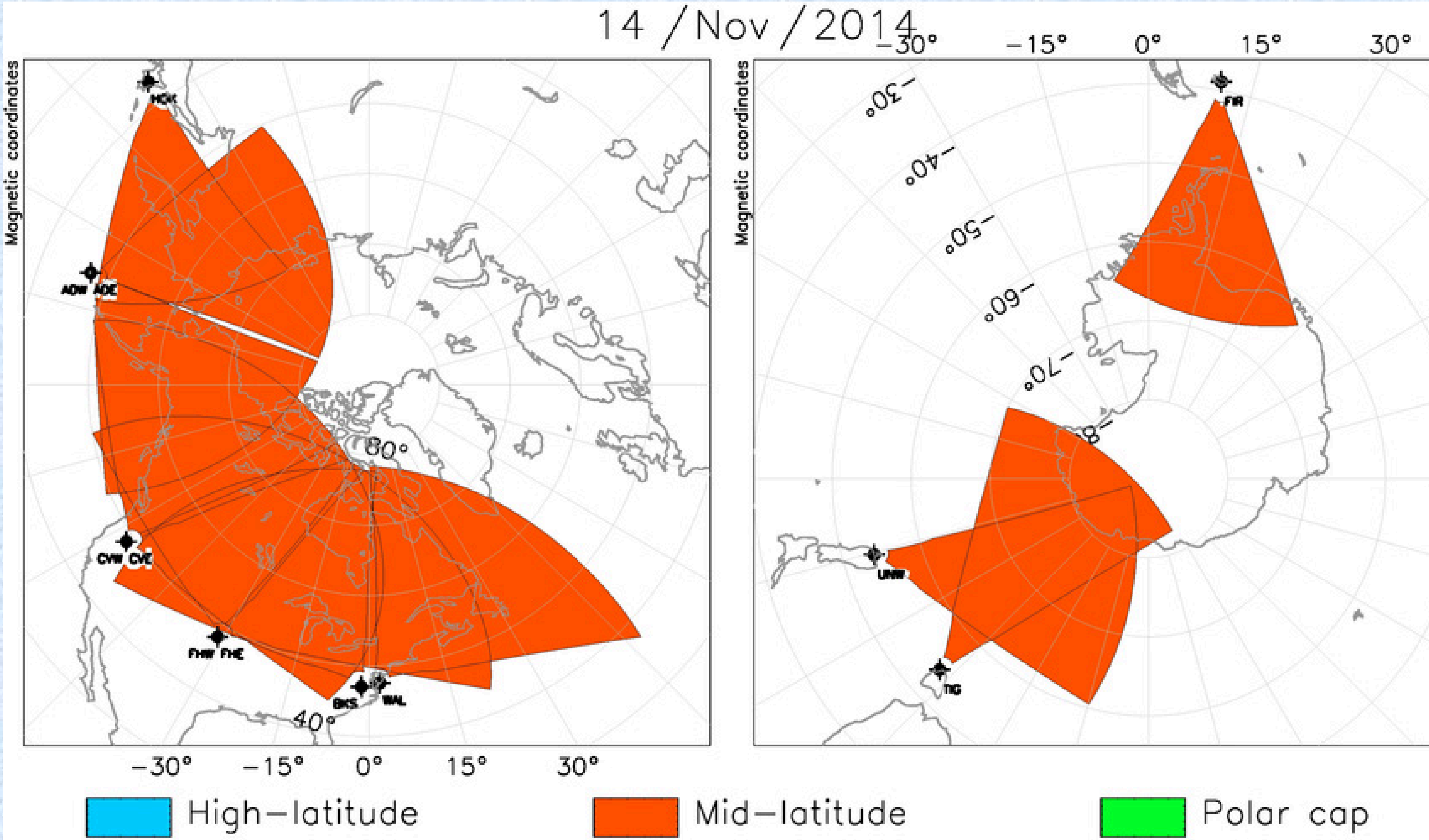


SuperDARN was developed mainly to measure ionospheric plasma convection

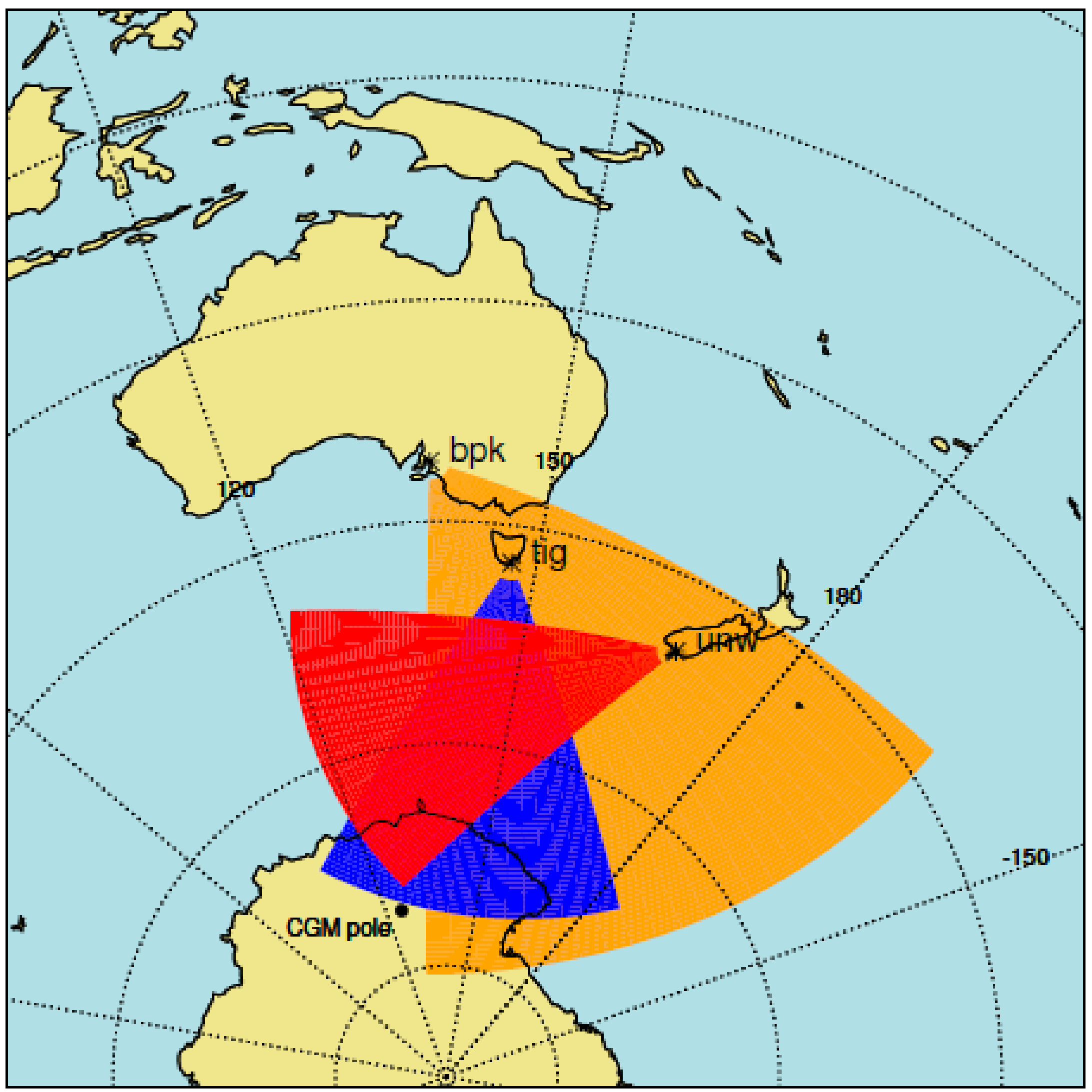


09:50 – 09:52 UT on 30th September 2002

A growing network of mid-latitude SuperDARN radars measures storm-related and other effects

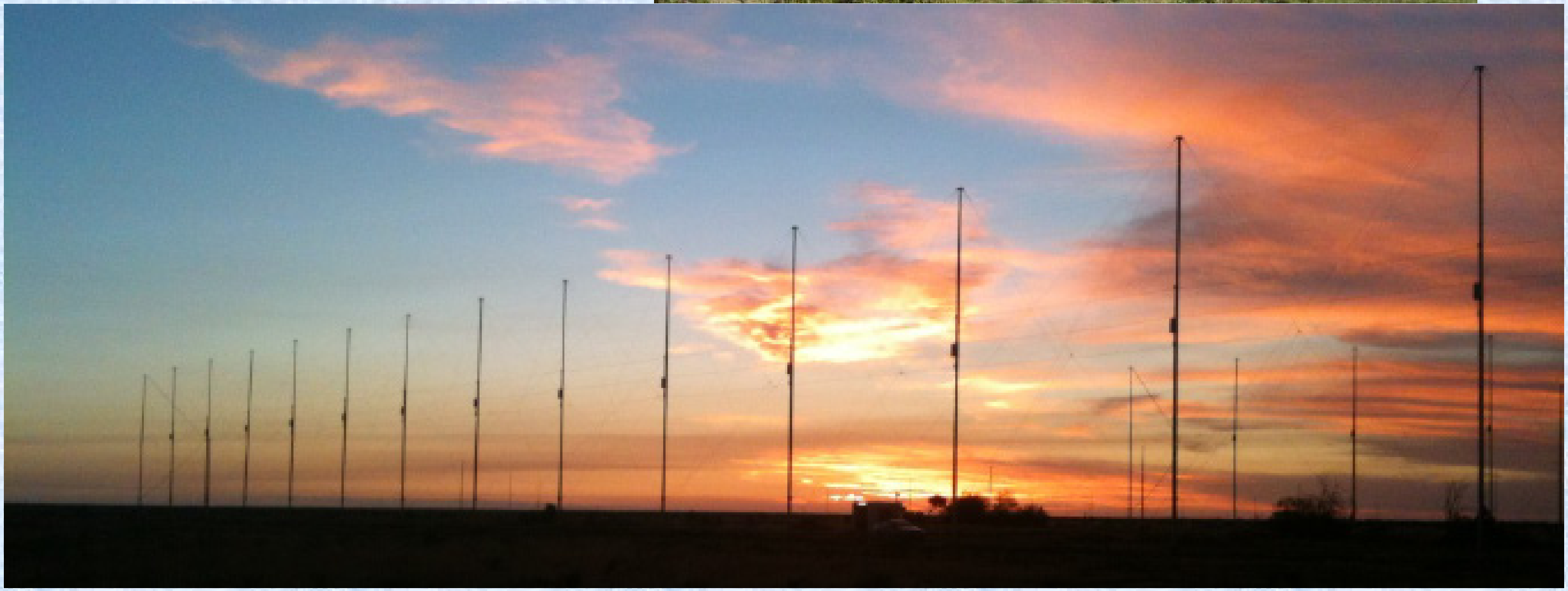


The TIGER array foms the lowest latitude SuperDARN radars



Footprints of the TIGER radars:
Bruny (blue), 1999-
Unwin (red), 2004-
Buckland Park (orange), 2014-.

Unwin (Invercargill) and Buckland Park (Adelaide)

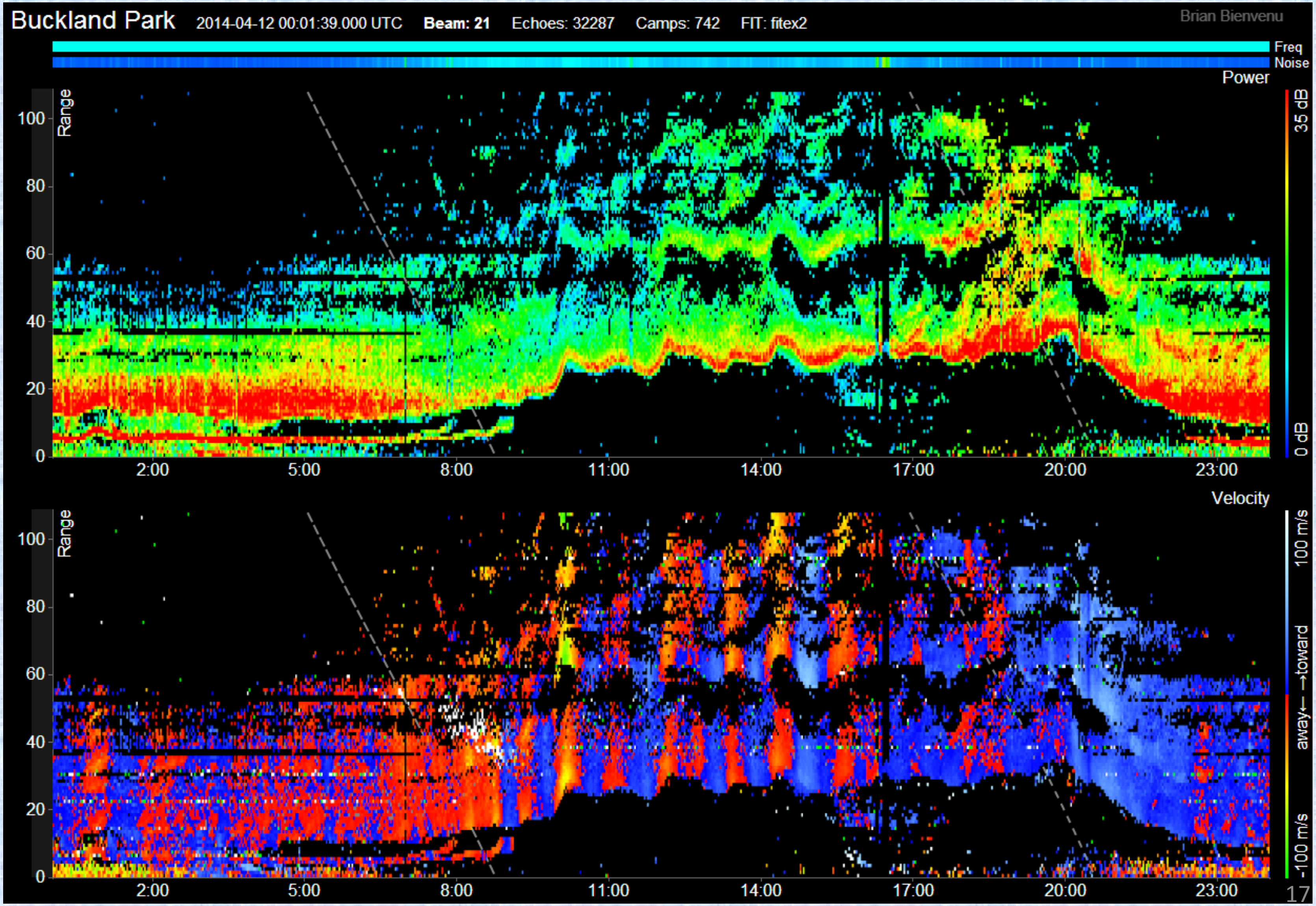


TIGER observations

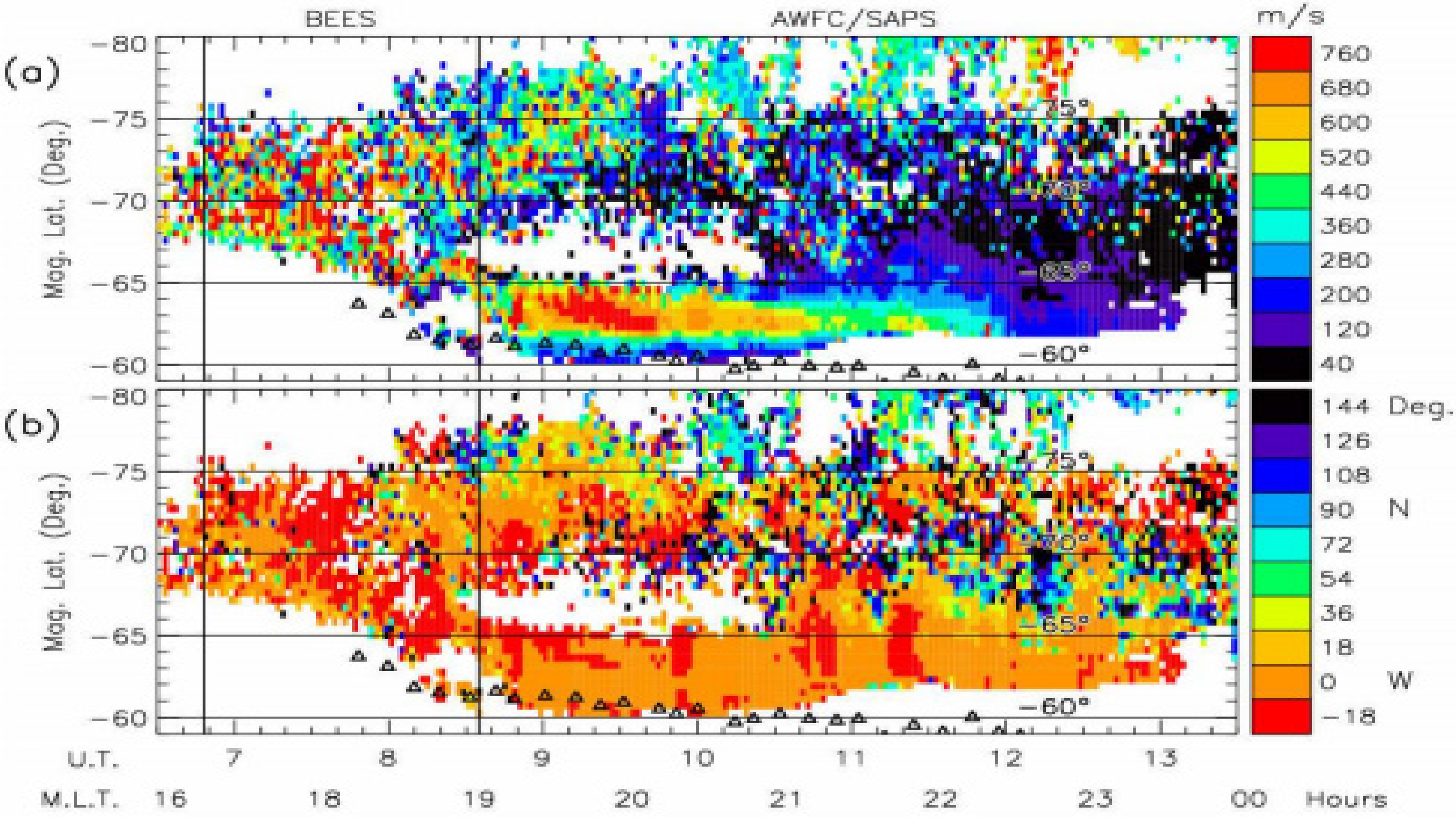
What we expect: F-region motions driven by field line resonances and drift-bounce resonances. What we see:

1. Complex storm-time motions at low latitudes.
2. Narrow westward convective flows associated with substorms and region 2 downward FAC. Equatorward edge is plasmapause proxy.
3. Highly coherent F-region oscillations due to plasma waves, associated with these westward flows and injection of ring current particles.
4. ~3 mHz discrete frequency oscillations near the plasmapause at quiet times.
5. Substorm-associated plasma oscillations driven by Pi2 pulsations.

Example Buckland Park range-time and velocity-time plot, 12 April 2014, late recovery phase of Kp=5- storm.

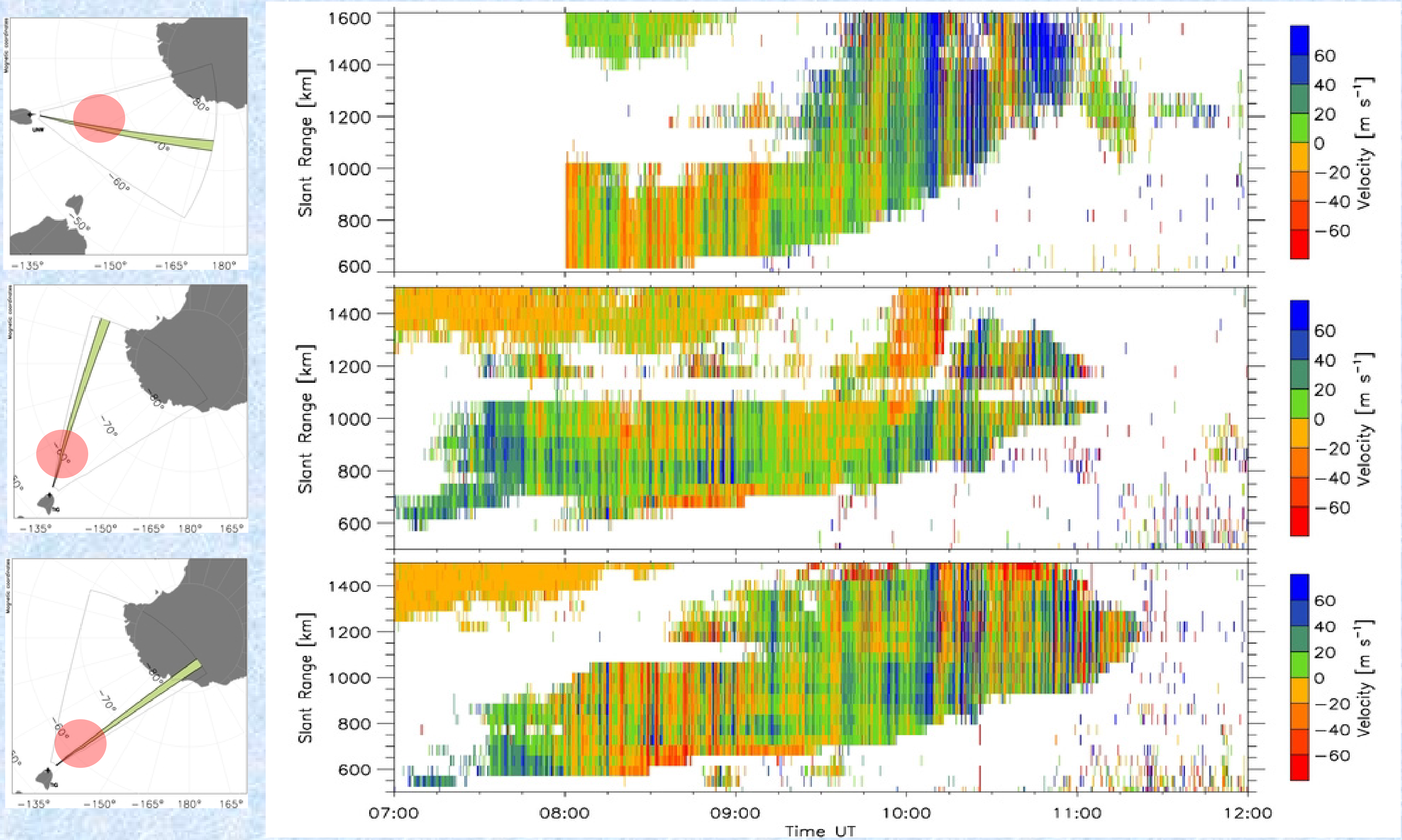


Westward F-region flows mapping to the plasmapause

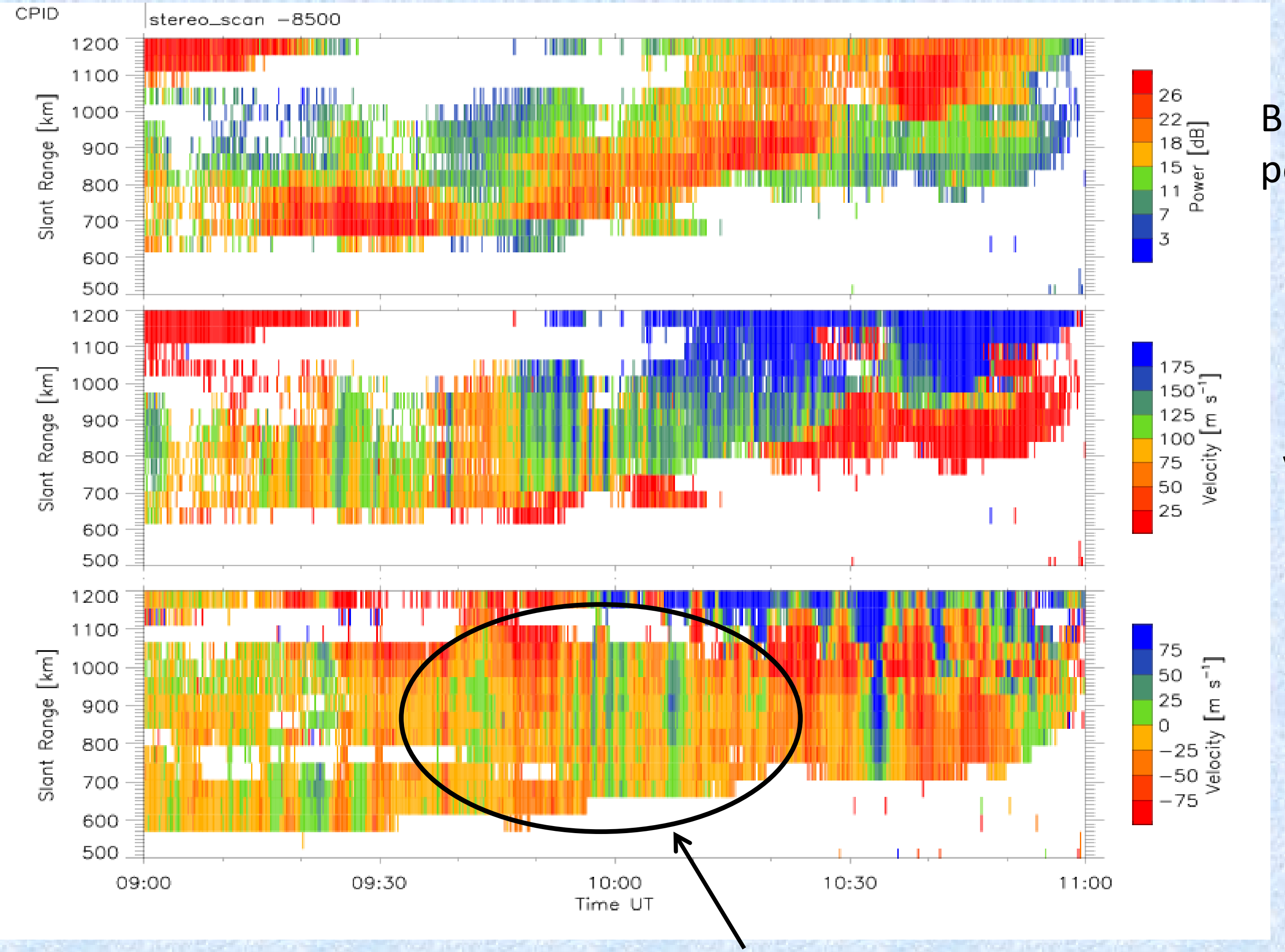


Flow speed (top) and direction (bottom) for TIGER beam 4 on 7 April 2001. Triangles represent plasmapause locations. Parkinson et al., AG, 2007.

F-region plasma motions driven by ULF waves: 8 April 2009.



F-region plasma motions driven by ULF waves: 15 Feb 2008.



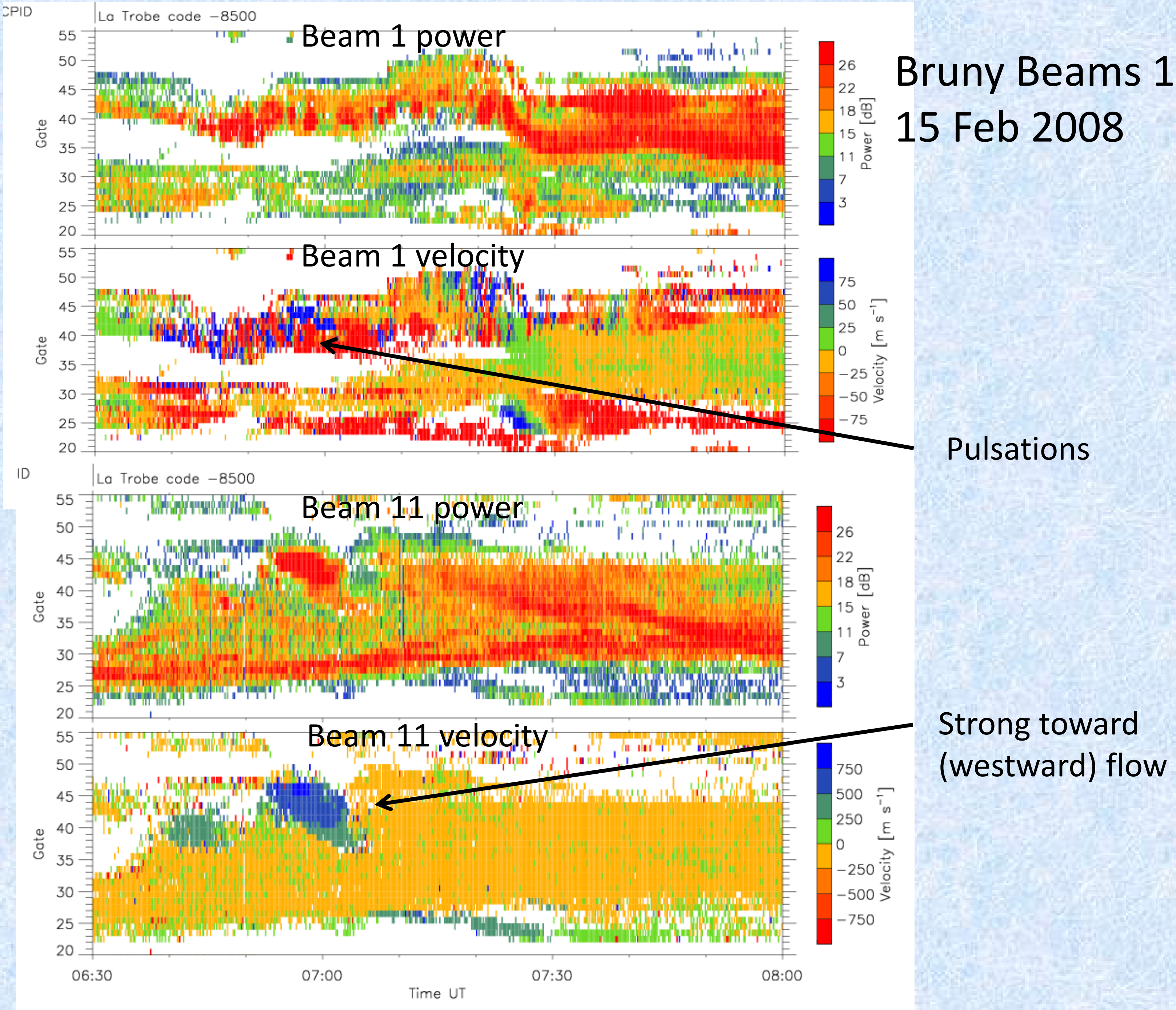
Bruny beam 14 power

Beam 14 velocity

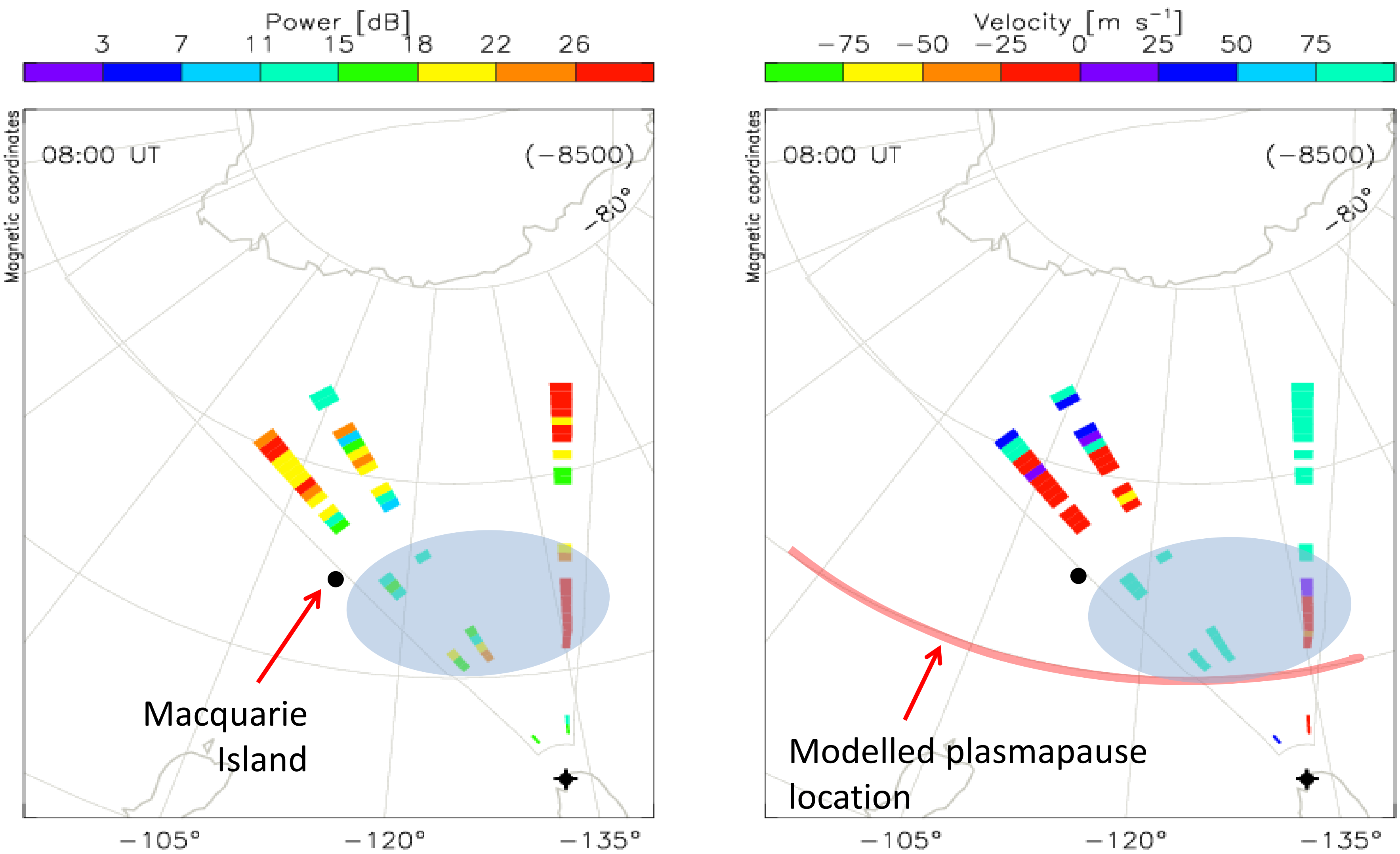
Beam 1 velocity

Wave features

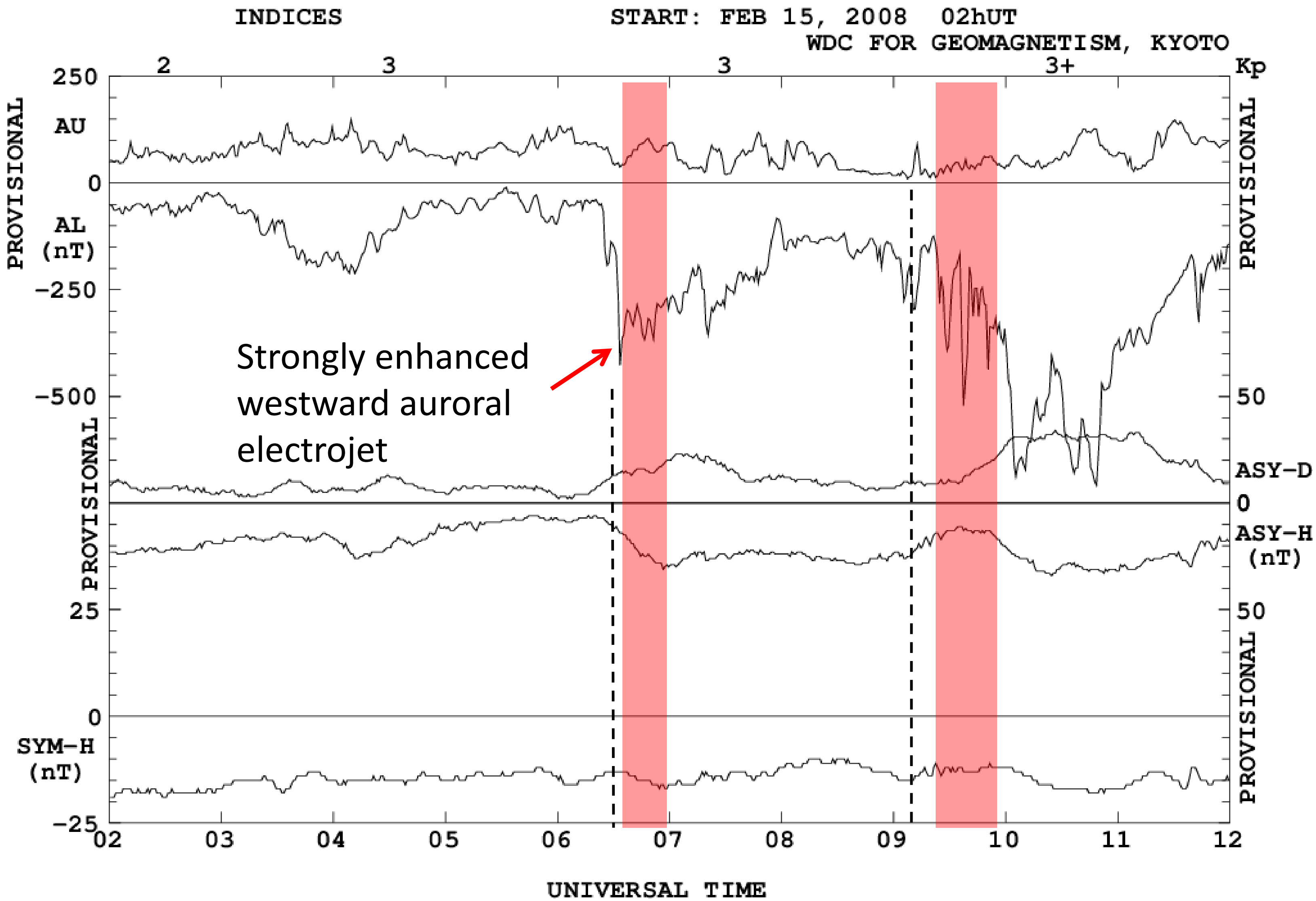
Bruny Beams 1 & 11
15 Feb 2008



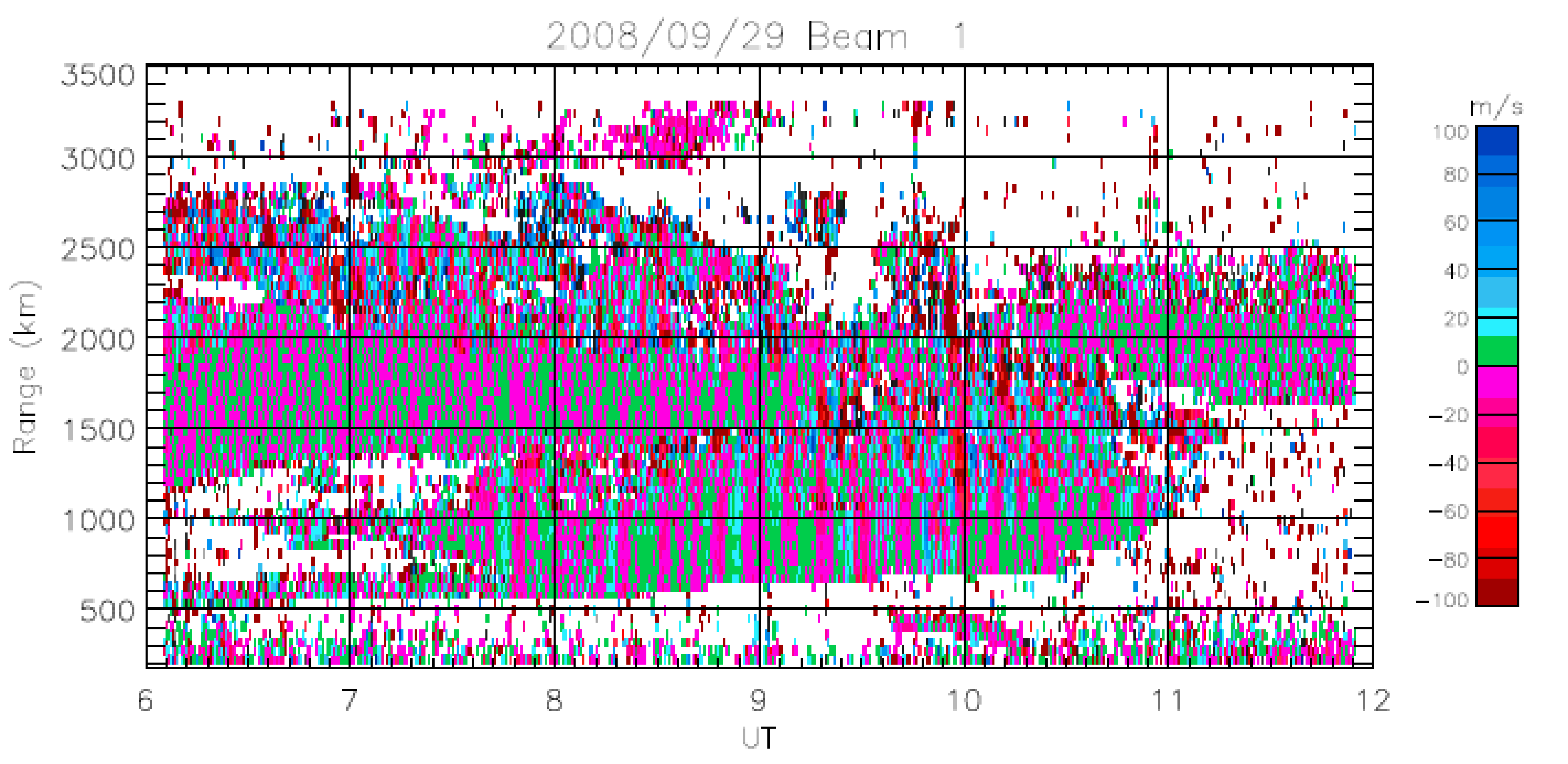
Scattering locations (CGM coordinates) for this event



Monitors of current systems



Typical example of discrete frequency oscillations in TIGER



Discrete frequency oscillations in TIGER-Bruny over 3 years

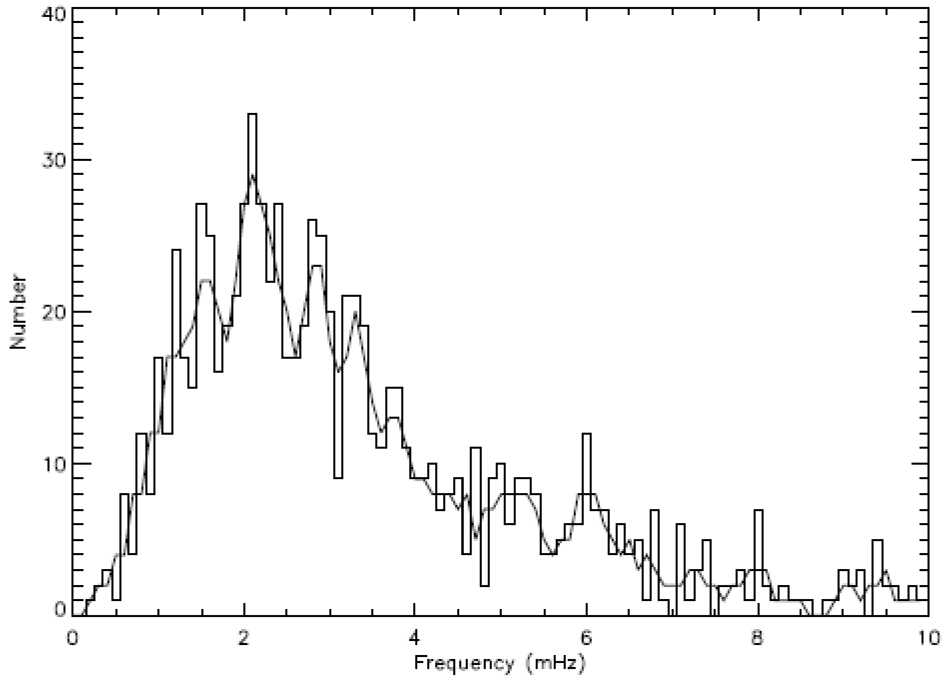
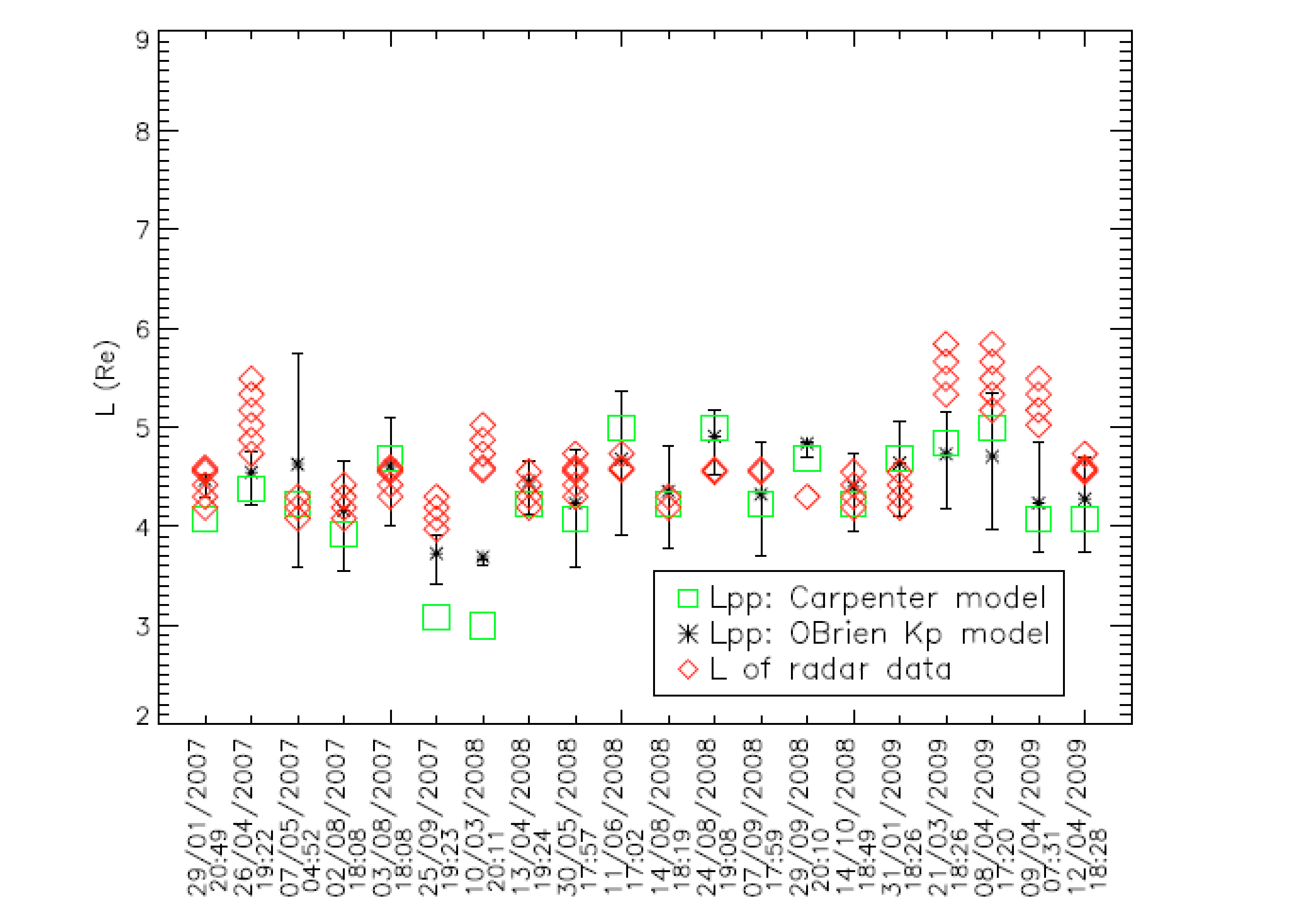


Figure 7. Histogram of significant frequencies in the radar data set. A 3-point smooth curve is also shown. Favored frequencies at 1.3, 1.6, 2.1, 2.7 and 3.3 and higher are seen. The frequency resolution is 0.1 mHz.

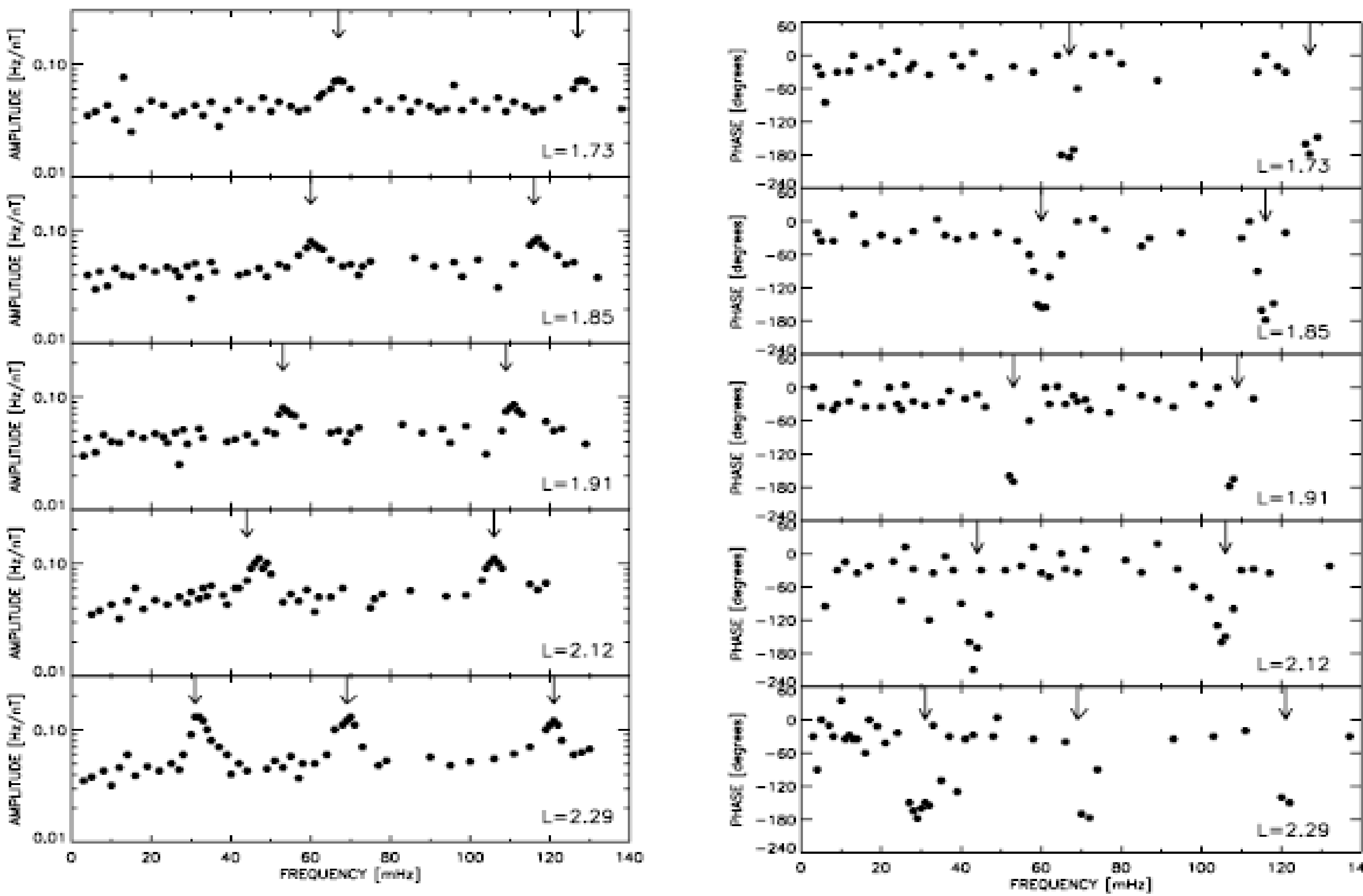
The discrete frequency oscillations appear to come from the projection of the plasmapause



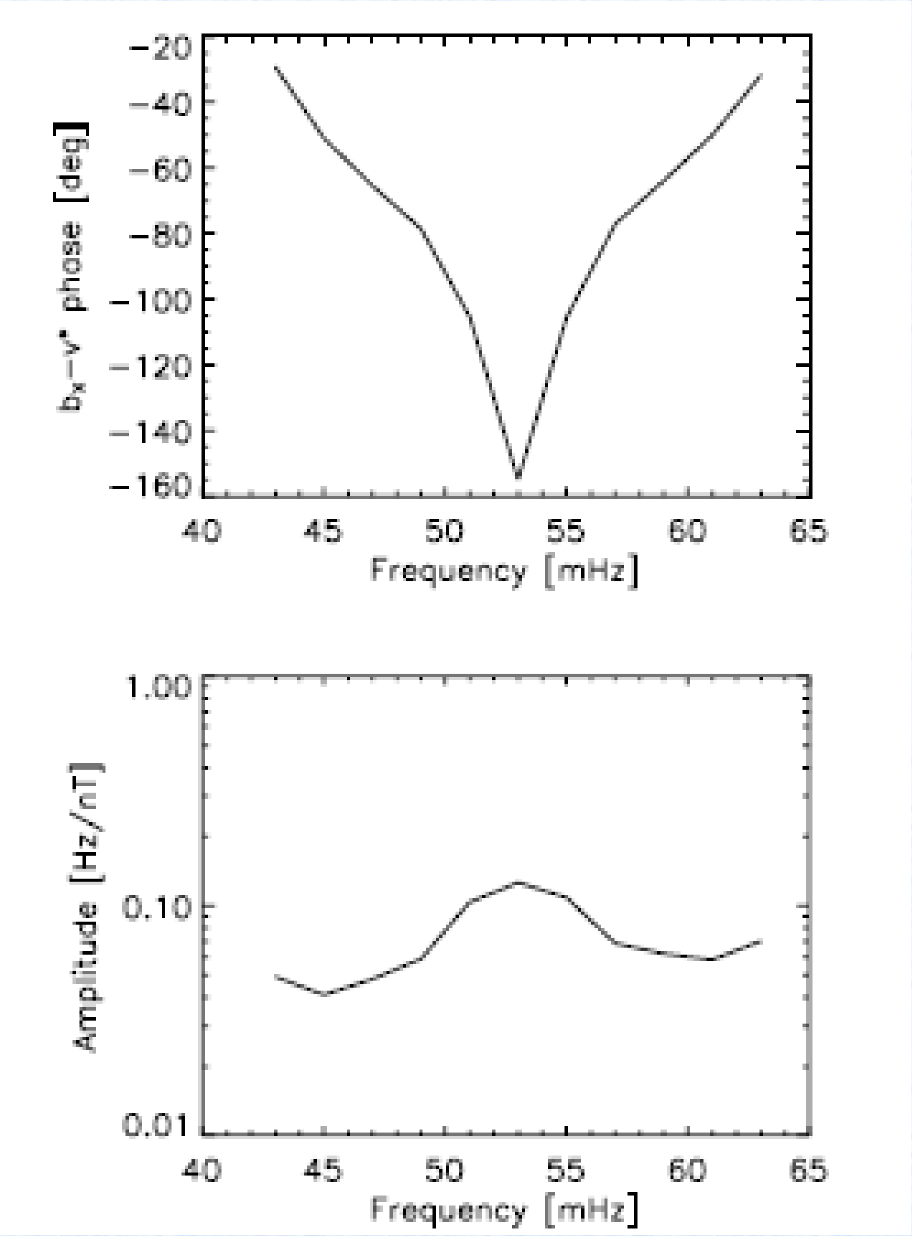
Progress on modelling

1. We have developed a 2-D model of interaction between plasma waves and the ionosphere. The model includes inclined B and downgoing wave mode mix. With suitable wave parameters this can replicate observations.
2. This forms the lower boundary of a 2-D model of wave propagation and coupling through the magnetosphere. This is the first model to include a realistic ionosphere, and can predict amplitude and phase variations at the ground.
3. We are now including particle motions, and moving the model to full 3-D.

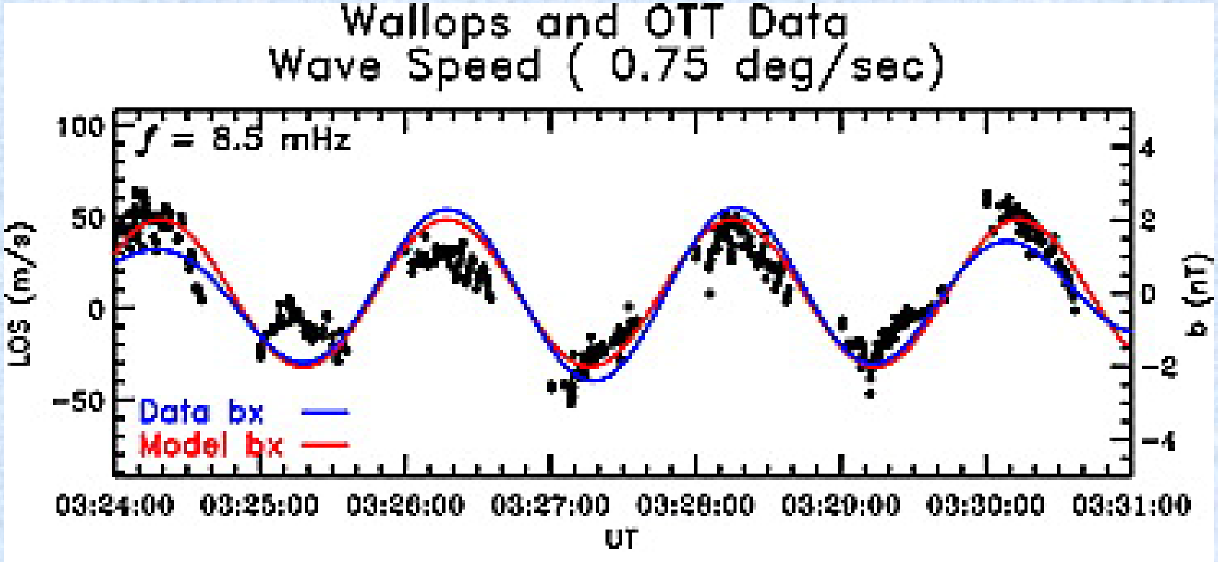
Amplitude and phase of oscillations in the low-latitude ionosphere and on the ground, 12 Jan 1994. Menk et al, GRL 2007.



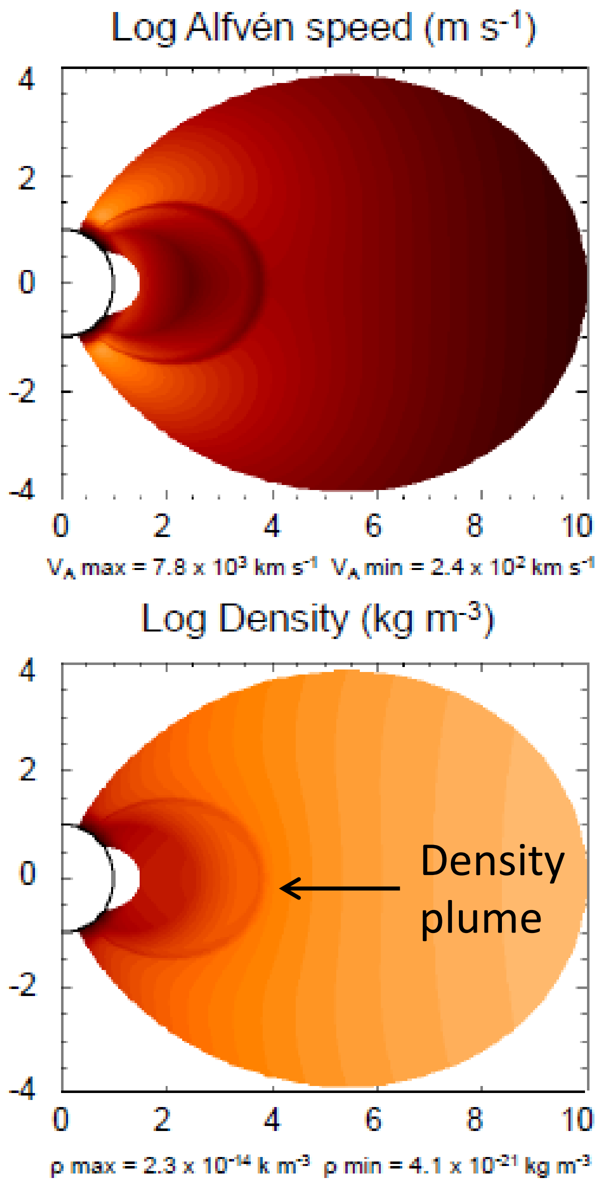
Modelled amplitude and phase of wave-driven ionospheric oscillations, assuming incident wave changes from 98% Alfven mode at 53 mHz to pure fast mode at 43 and 63 mHz.

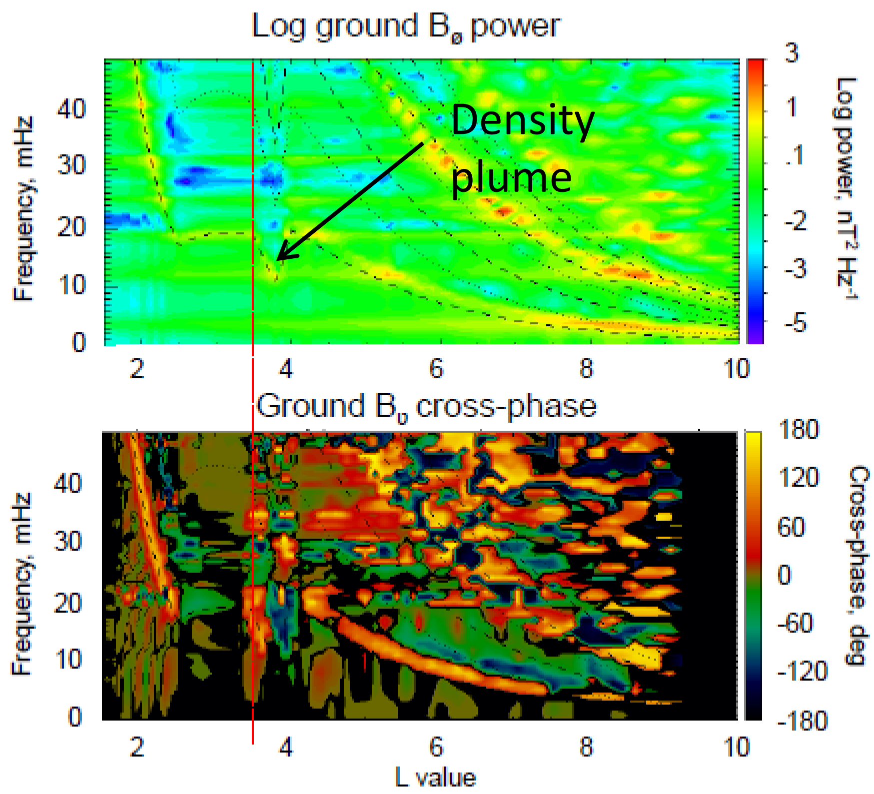


Wallops HF radar line-of-sight drift velocities for a substorm associated Pi2 event (black dots), ground magnetic field perturbation bx (blue) and modelled ground field perturbation (red). Gjerloev et al., GRL, 2007.



2 ½ D model of plasma wave propagation through magnetosphere using realistic density and boundary conditions (left), to confirm and predict ground magnetometer signatures of plasma plumes (below).





Summary

- Mid-latitude radars monitor the projection to the ionosphere of ring current and M-P-I coupling events
- Effects are observed include convective flows near the plasmapause, substorm particle injections, and magnetospheric plasma waves
- At least some of these effects have user impacts (e.g. Doppler clutter in surveillance radars)
- Modelling of the propagation of plasma waves through the magnetosphere can (with input of observational parameters) simulate plasma motions seen by radars
- Other effects await explanation


Questions?