HAARP Generated ELF/VLF Waves for Magnetospheric Probing

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Outline

- HAARP magnetospheric wave injection experiment
- Survey of geomagnetic indices (Kp, DST, AE)
- Relation to concurrent natural magnetospheric emissions
- Most recent HAARP campaign
- Modeling of wave injection

Wave Injection with HAARP

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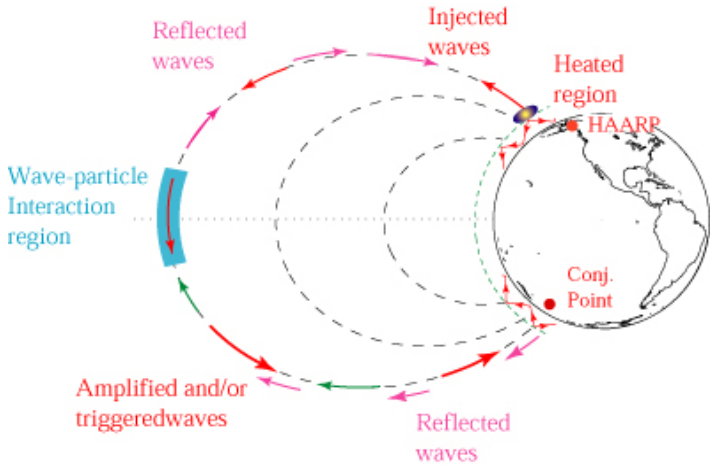
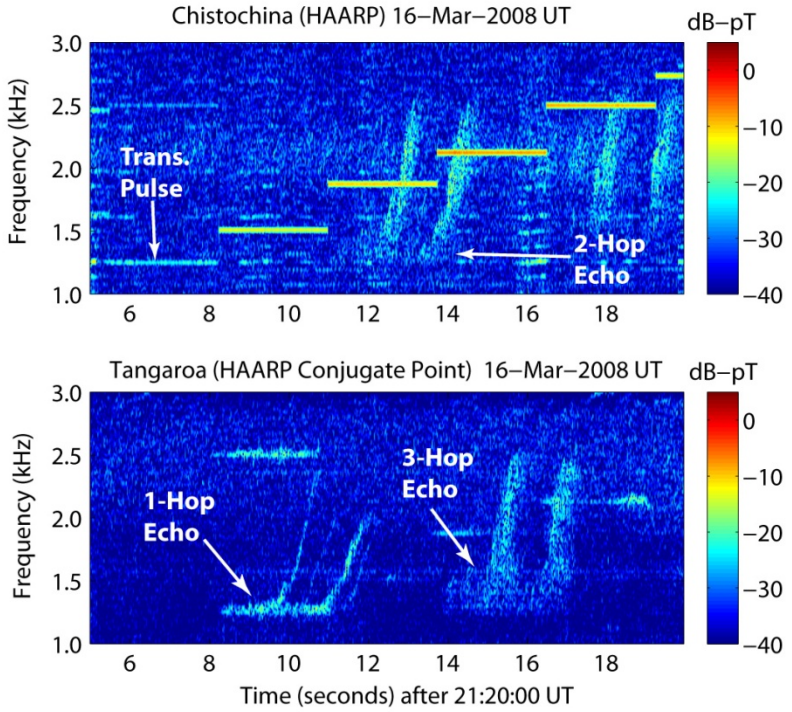
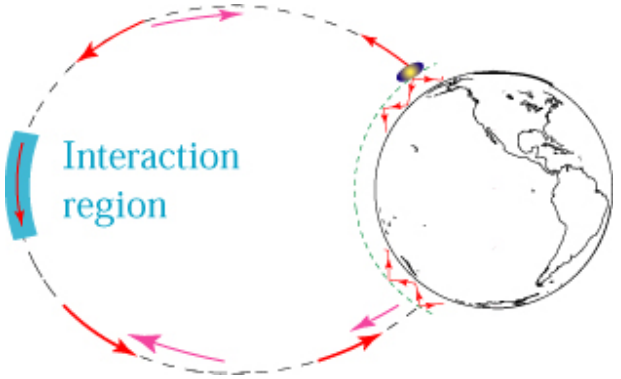
- HAARP generated ELF/VLF waves injected into the magnetosphere
- ELF/VLF waves undergo non-linear interaction with hot plasma electrons in magnetosphere
- Amplified waves observed on both ends of the magnetic field line



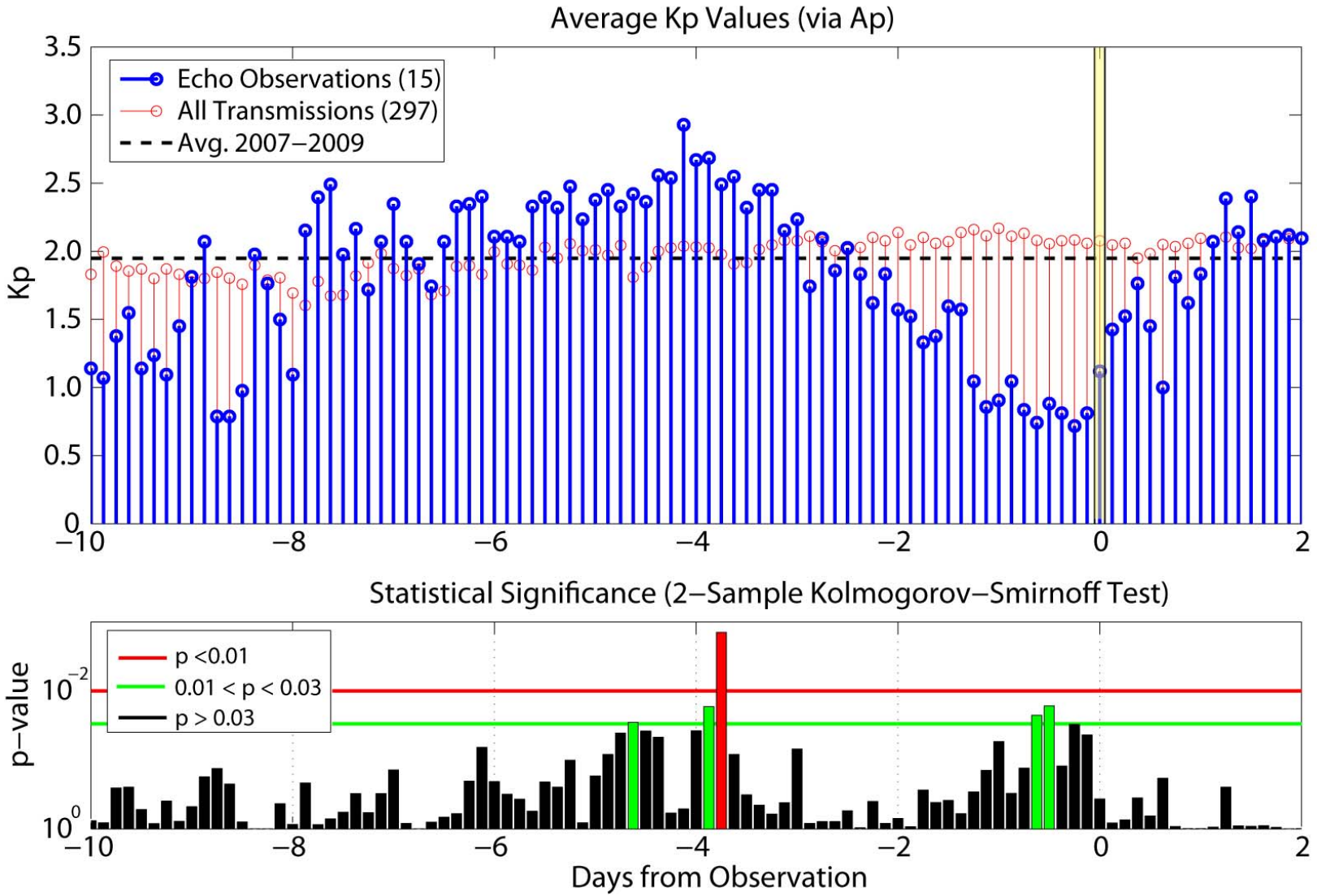


‘Learning to Amplify’

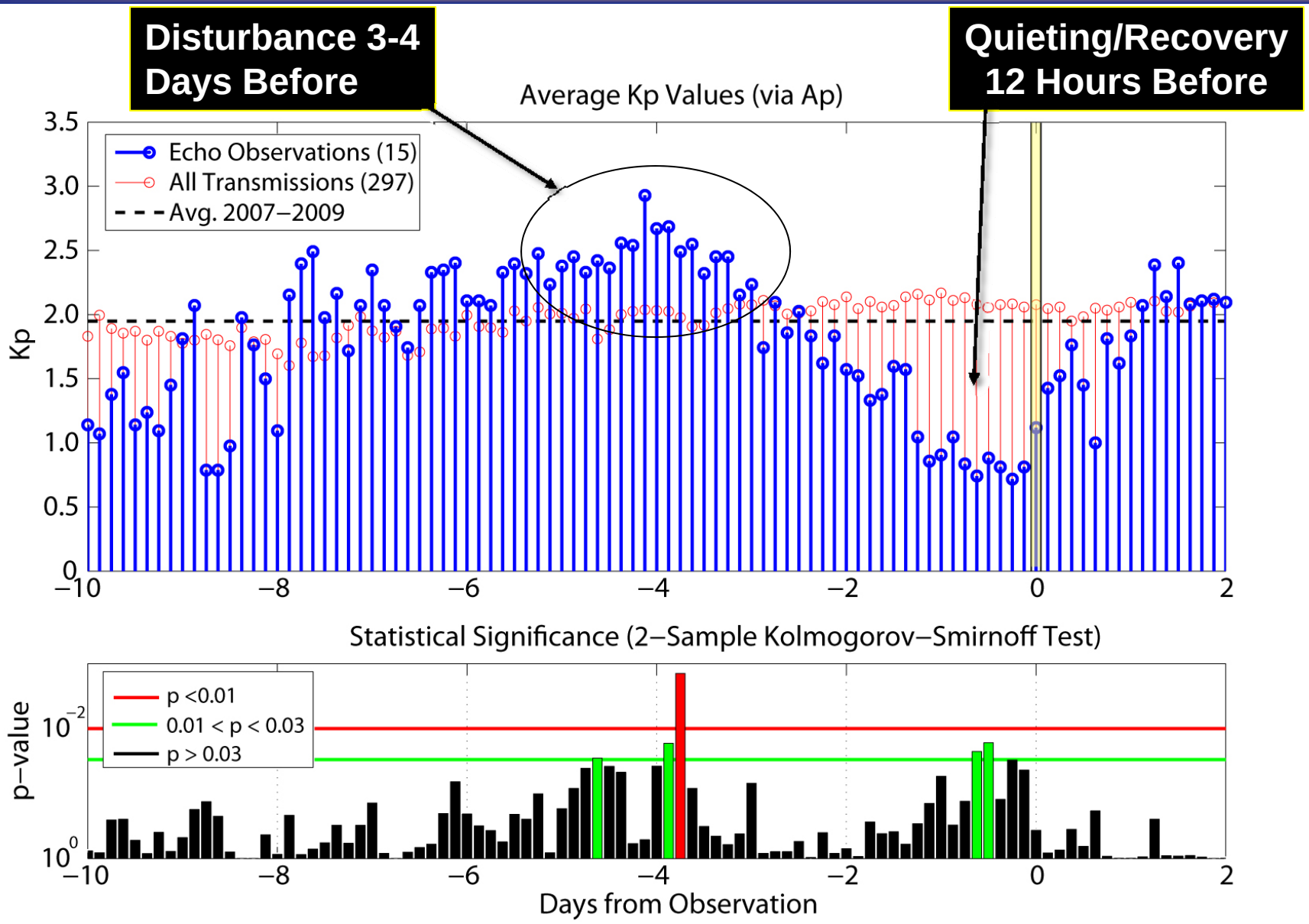
Under what conditions do ELF/VLF waves in the Earth’s magnetosphere experience non-linear amplification?



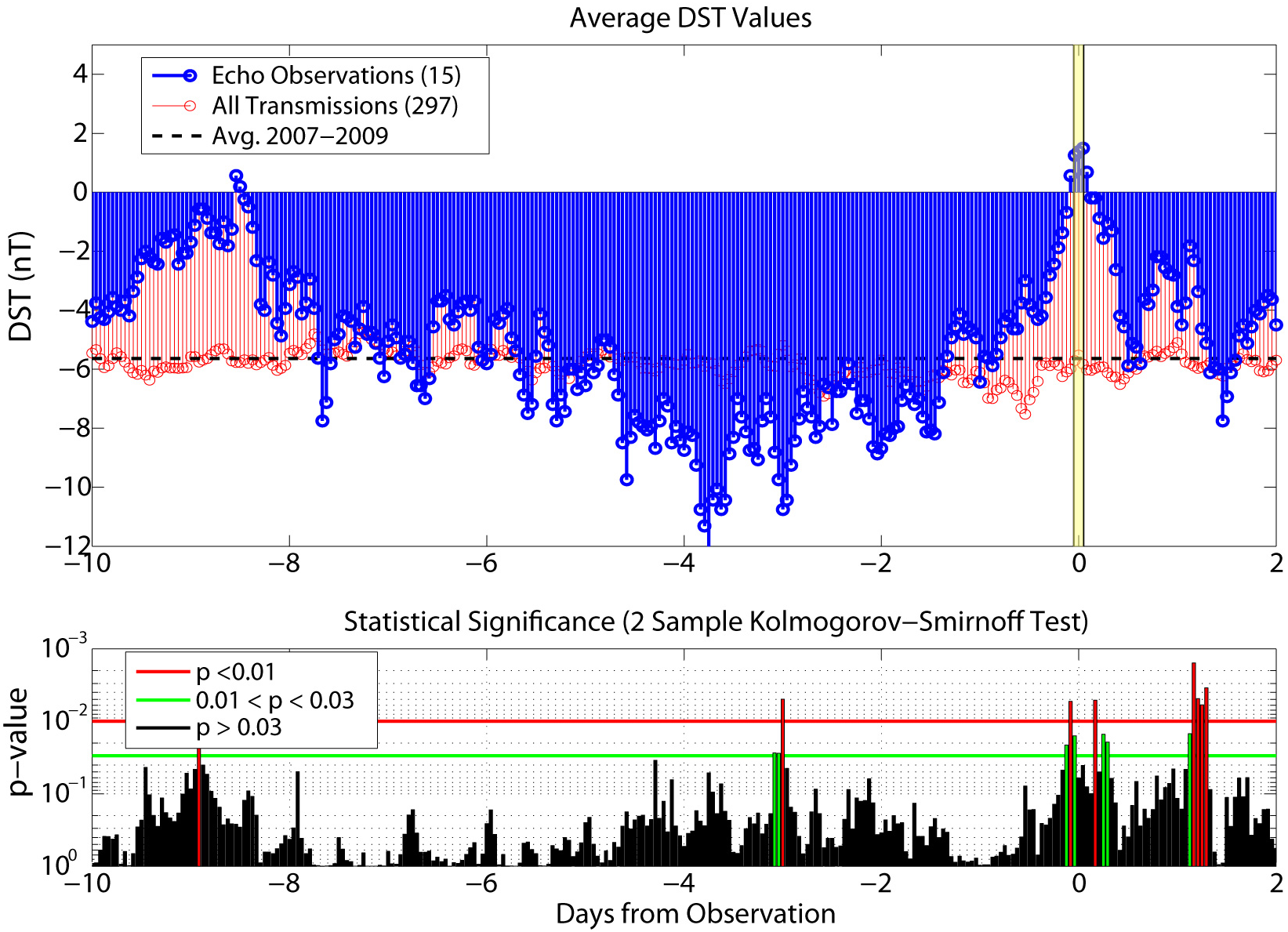
Geomagnetic Conditions: Kp



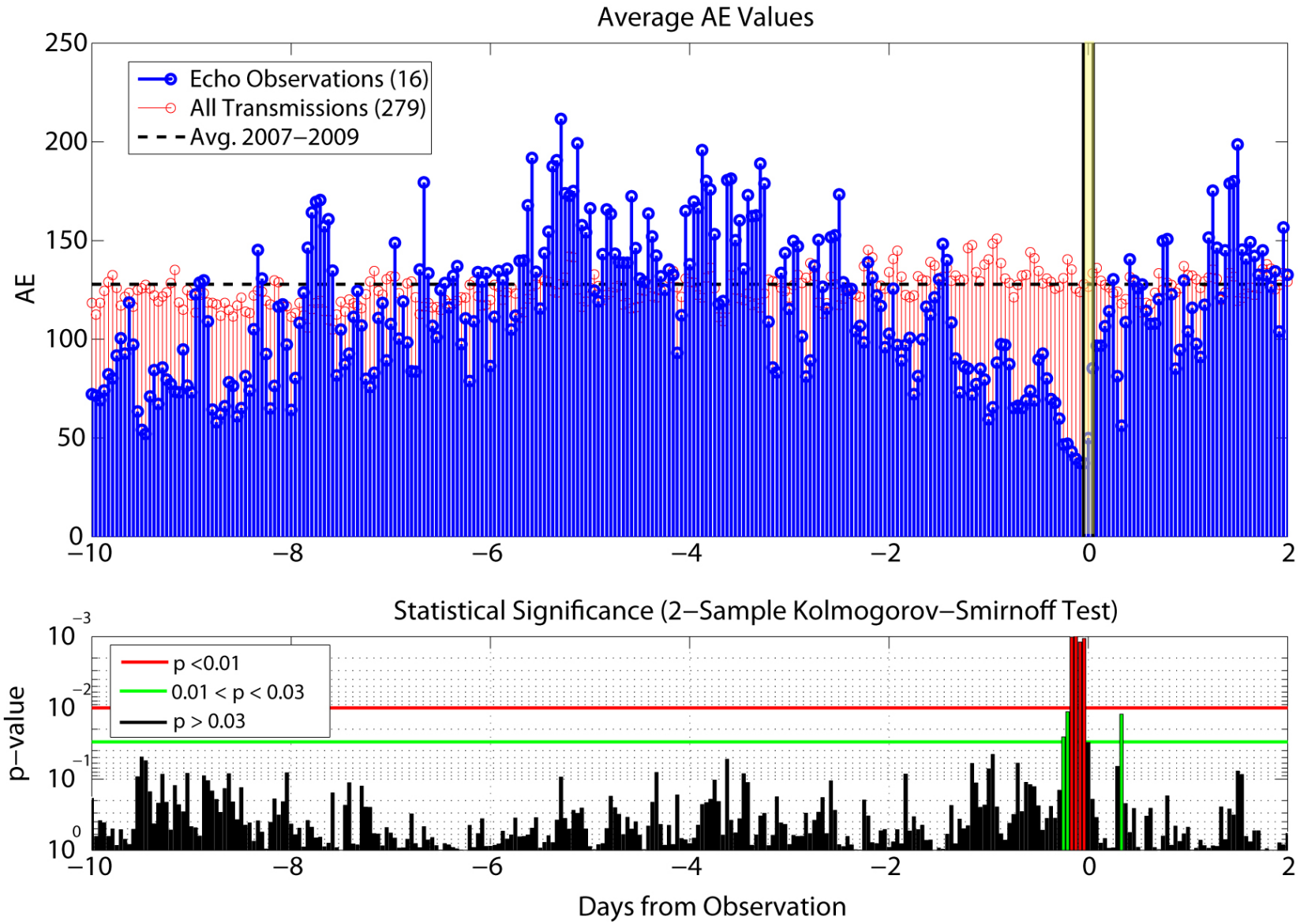
Geomagnetic Conditions: Kp



Geomagnetic Conditions: DST



Geomagnetic Conditions: AE

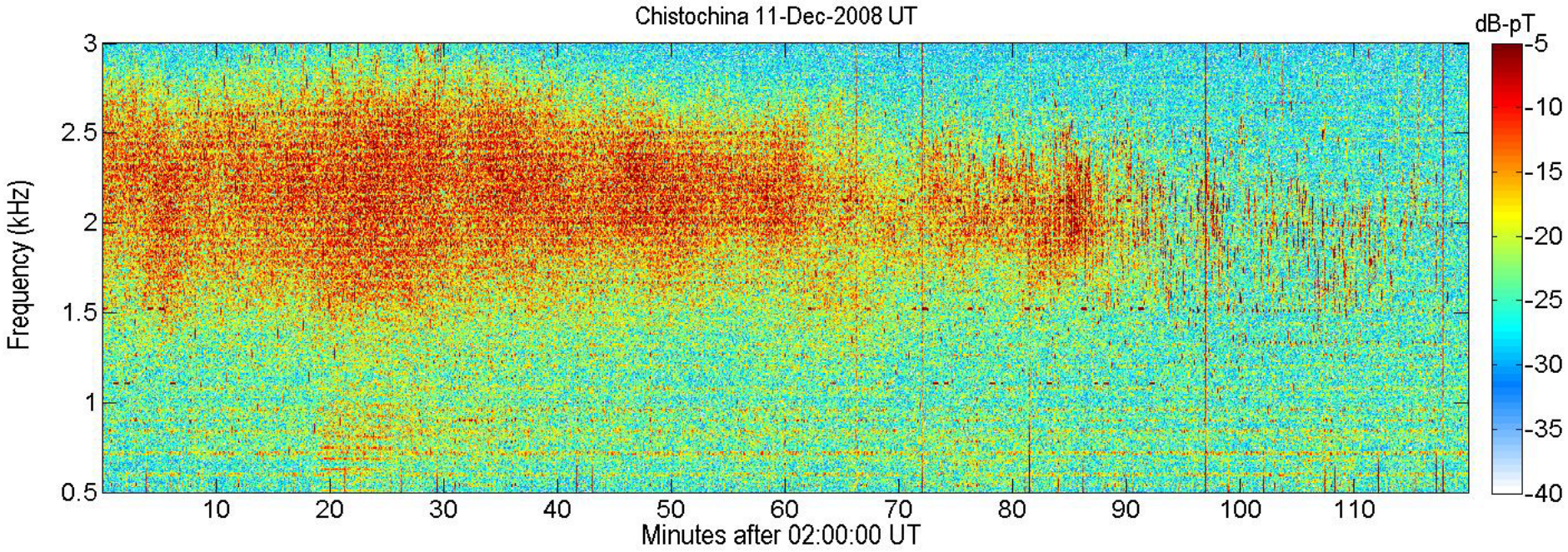


Relationship to Geomagnetic Indices

- Kp, DST, AE: quiet conditions 12-36 hours before observations are statistically significant, AE index most significant
- Kp and DST additionally show disturbed conditions 2-4 days prior to be significant

Not prolonged quiet but quieting/recovering conditions following a disturbance are most favorable for ground observations of HAARP induced magnetospheric amplification

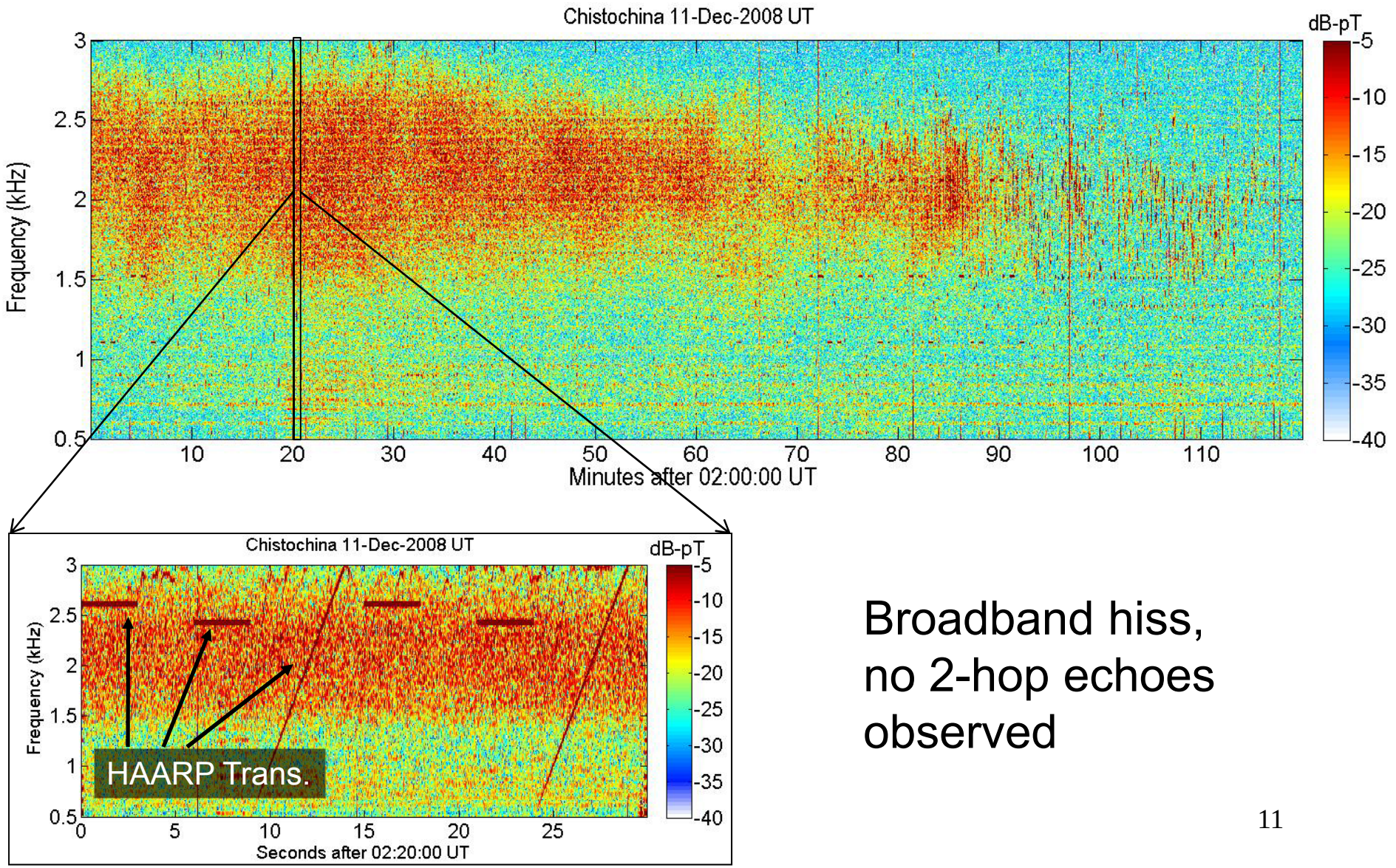
Two Hour Evolution



Unique ground observation

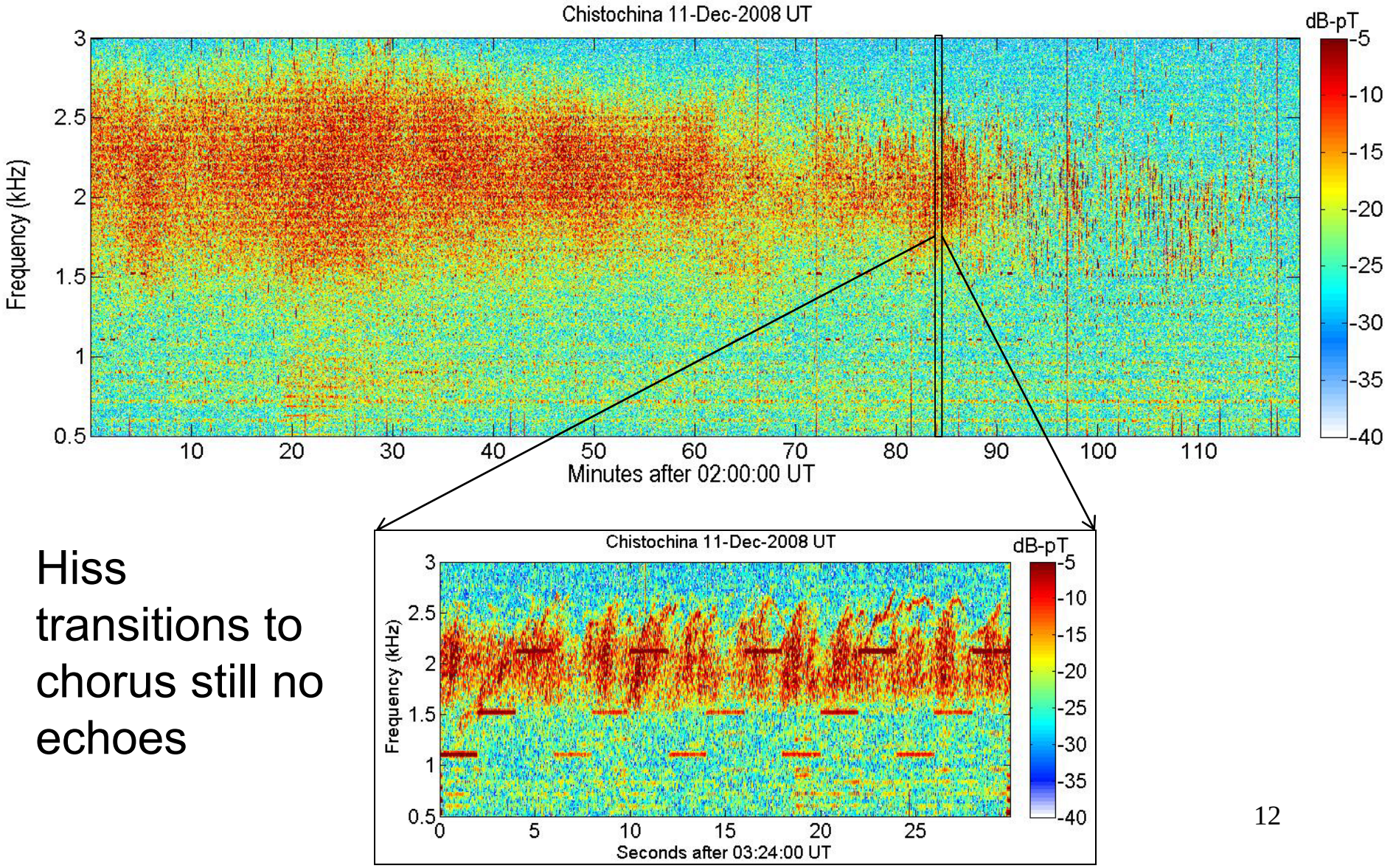
Natural broadband incoherent 'hiss' → Natural discrete 'chorus' → HAARP induced 'echoes' → No emissions

Two Hour Evolution: Hiss



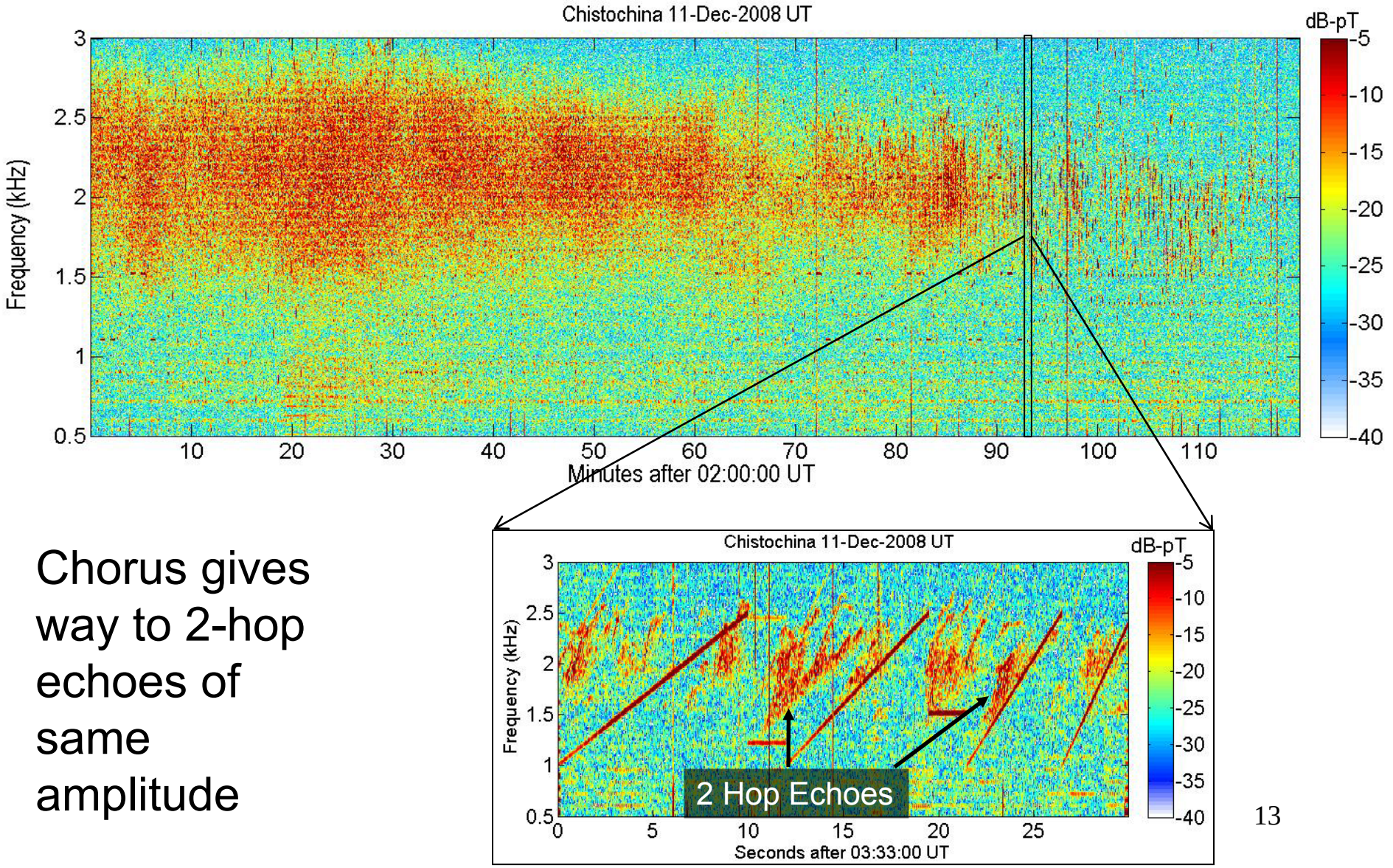
Broadband hiss,
no 2-hop echoes
observed

Two Hour Evolution: Chorus



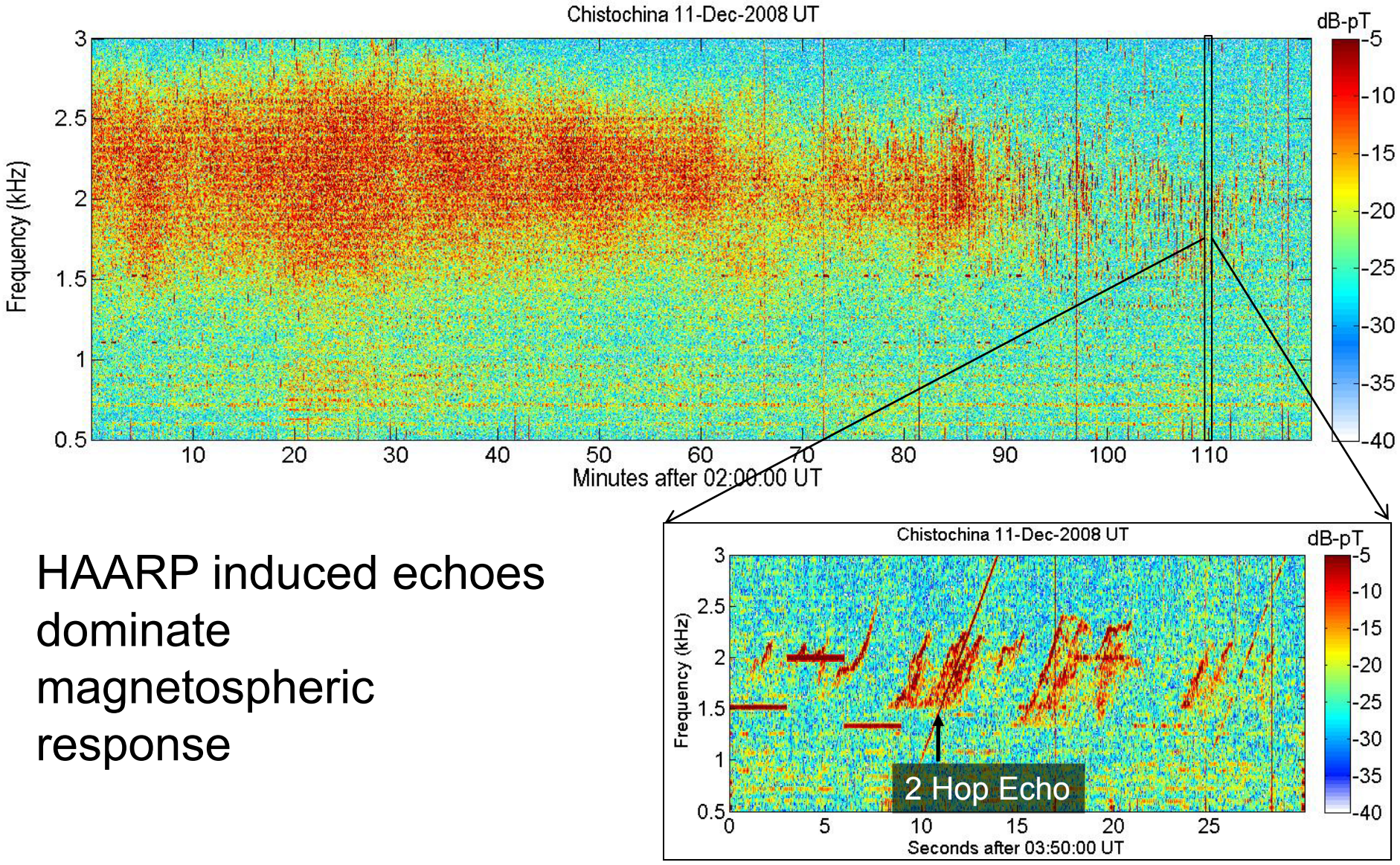
Hiss transitions to chorus still no echoes

Two Hour Evolution: Echoes



Chorus gives way to 2-hop echoes of same amplitude

Two Hour Evolution: Echoes



HAARP induced echoes dominate magnetospheric response

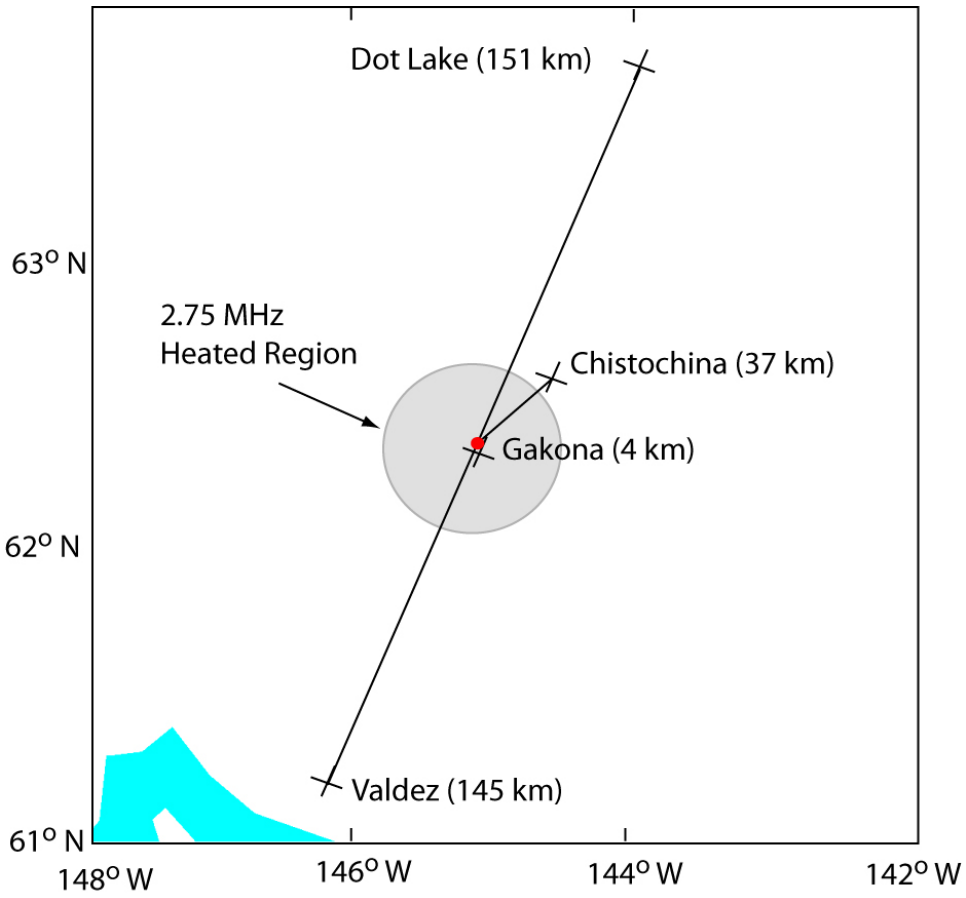
Significance of Natural Emissions to Amplification

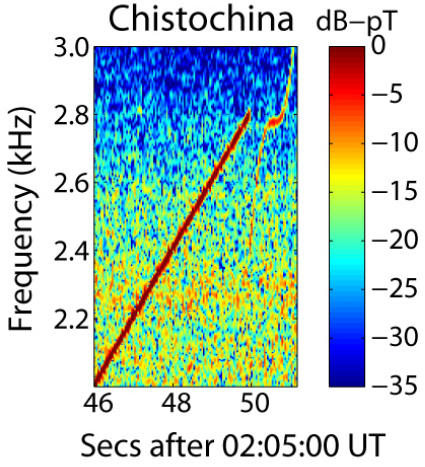
- Association of hiss, chorus, triggered emissions (1-hop, 2-hop echoes) previously observed

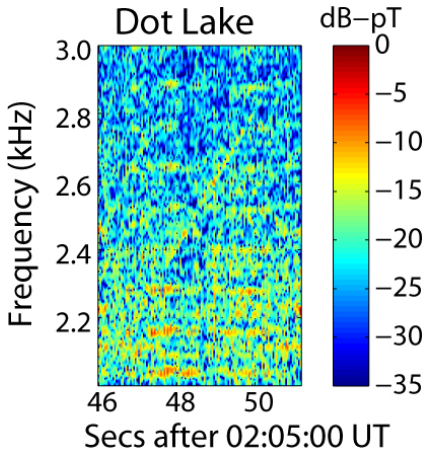
- Is the relationship
  - Causal through wave-particle interactions: hiss -> chorus [*Koons et al., JGR*, 1981] ?
  - Effect of propagation and dispersion: chorus ->hiss [*Bortnik et al., Nature*, 2008] ?
  - Linear (hiss) versus non-linear (chorus, echoes) radiation of free energy from anisotropy of electron distribution [*Omura et al., JGR*, 2008] ?

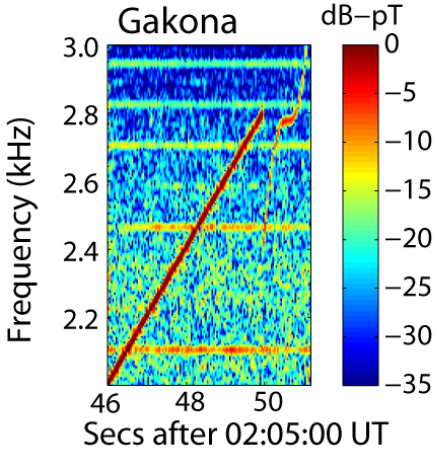
- Do observed emissions originate from the same place?

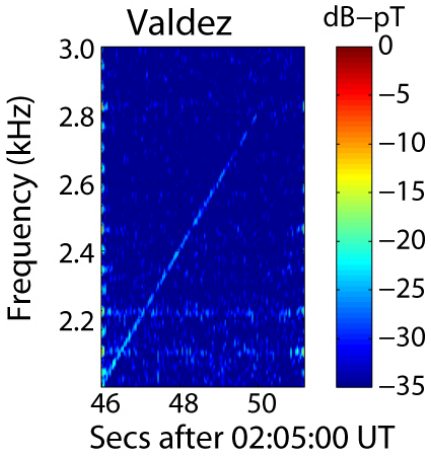
Multiple Site Measurements



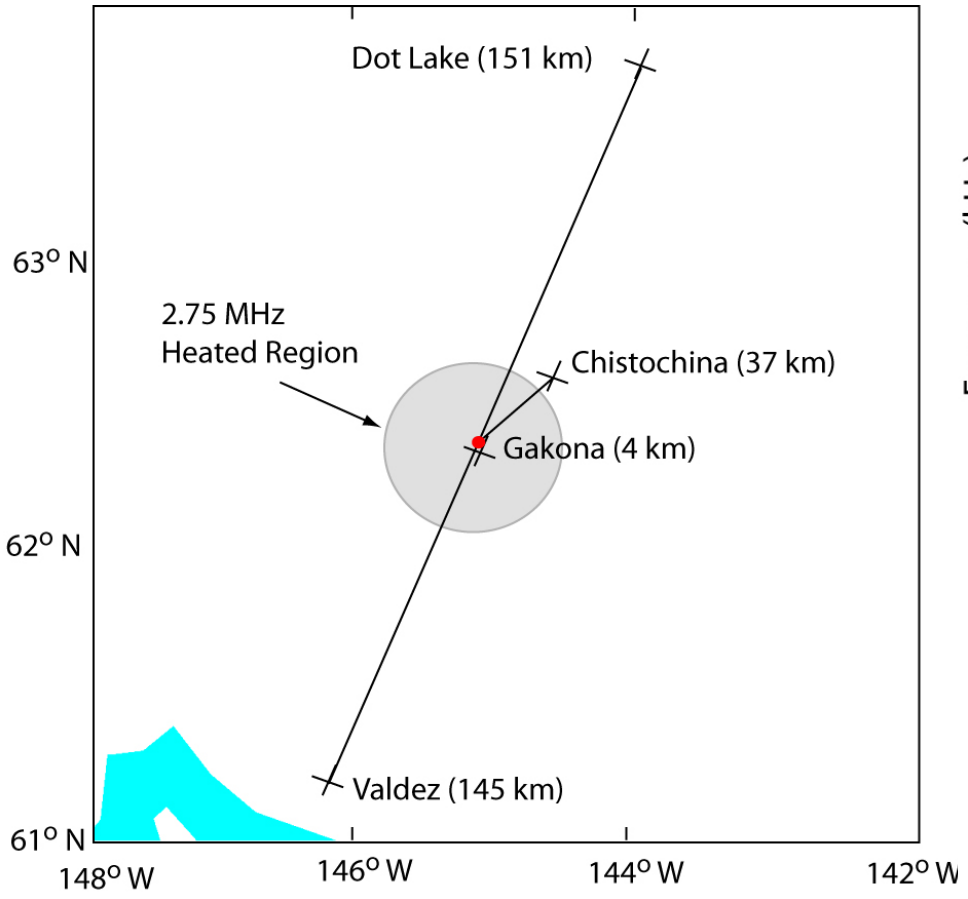


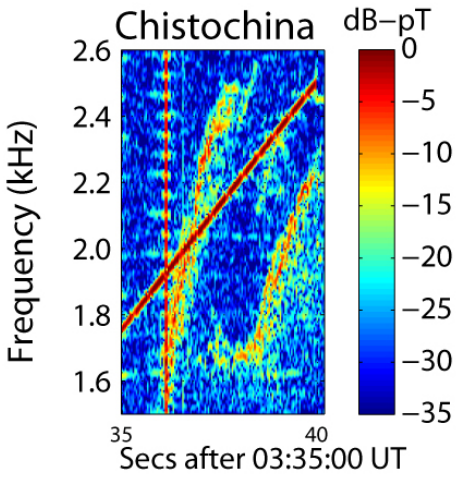


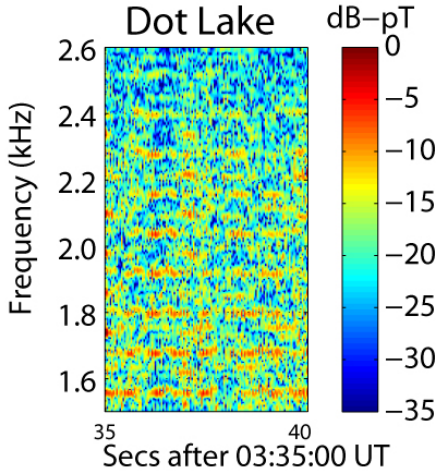


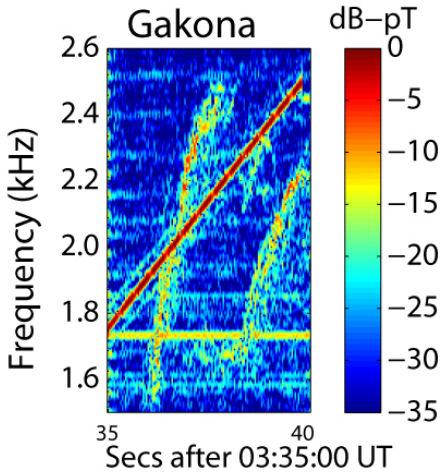


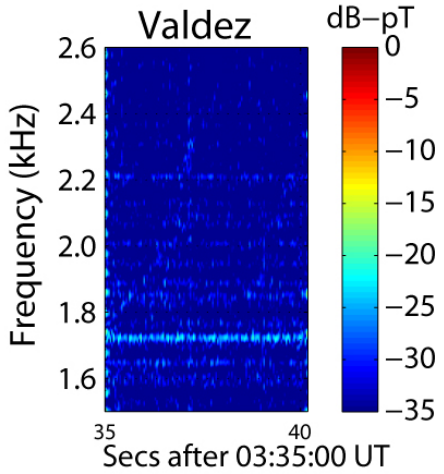
Source Location: Emissions





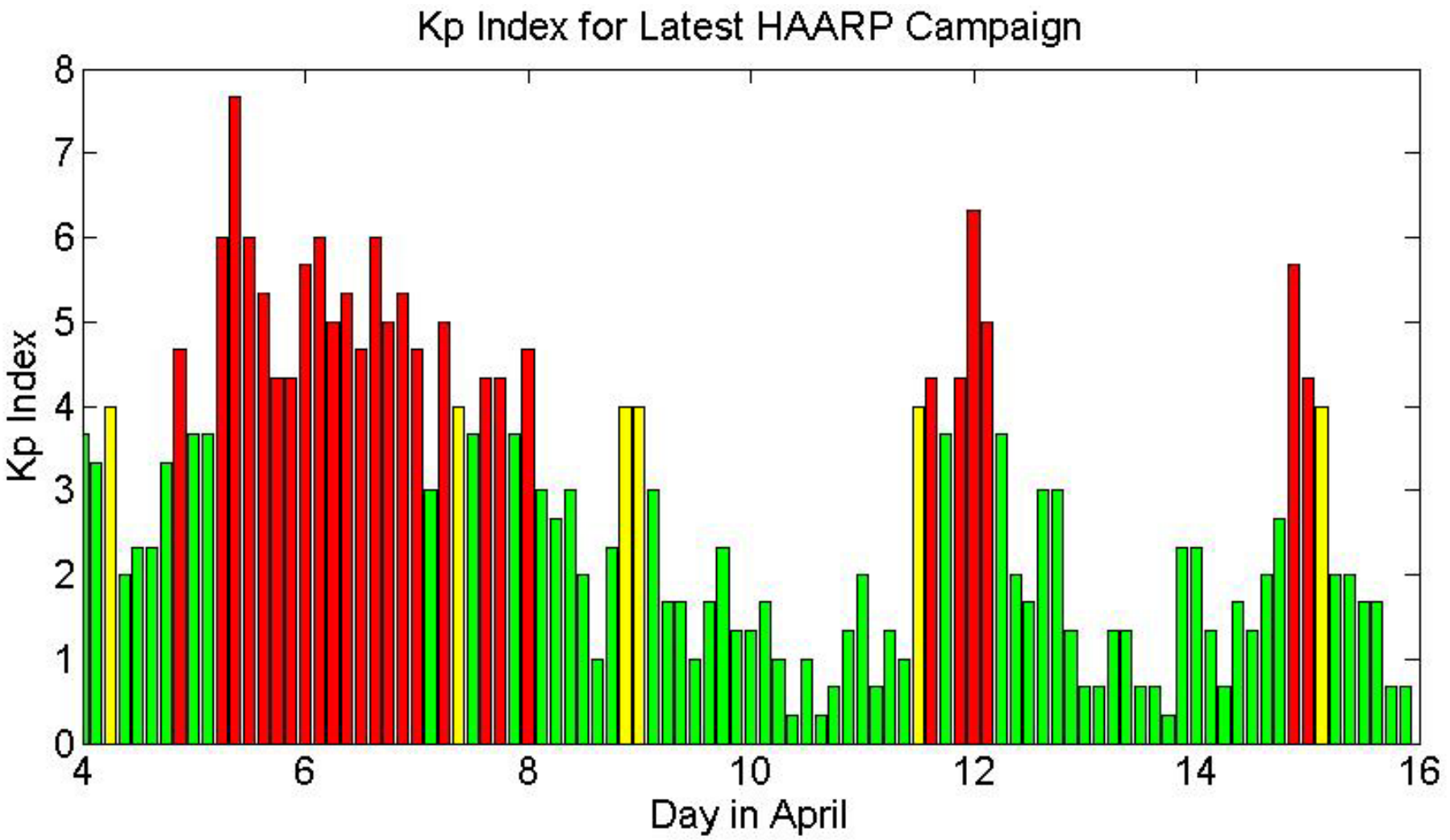




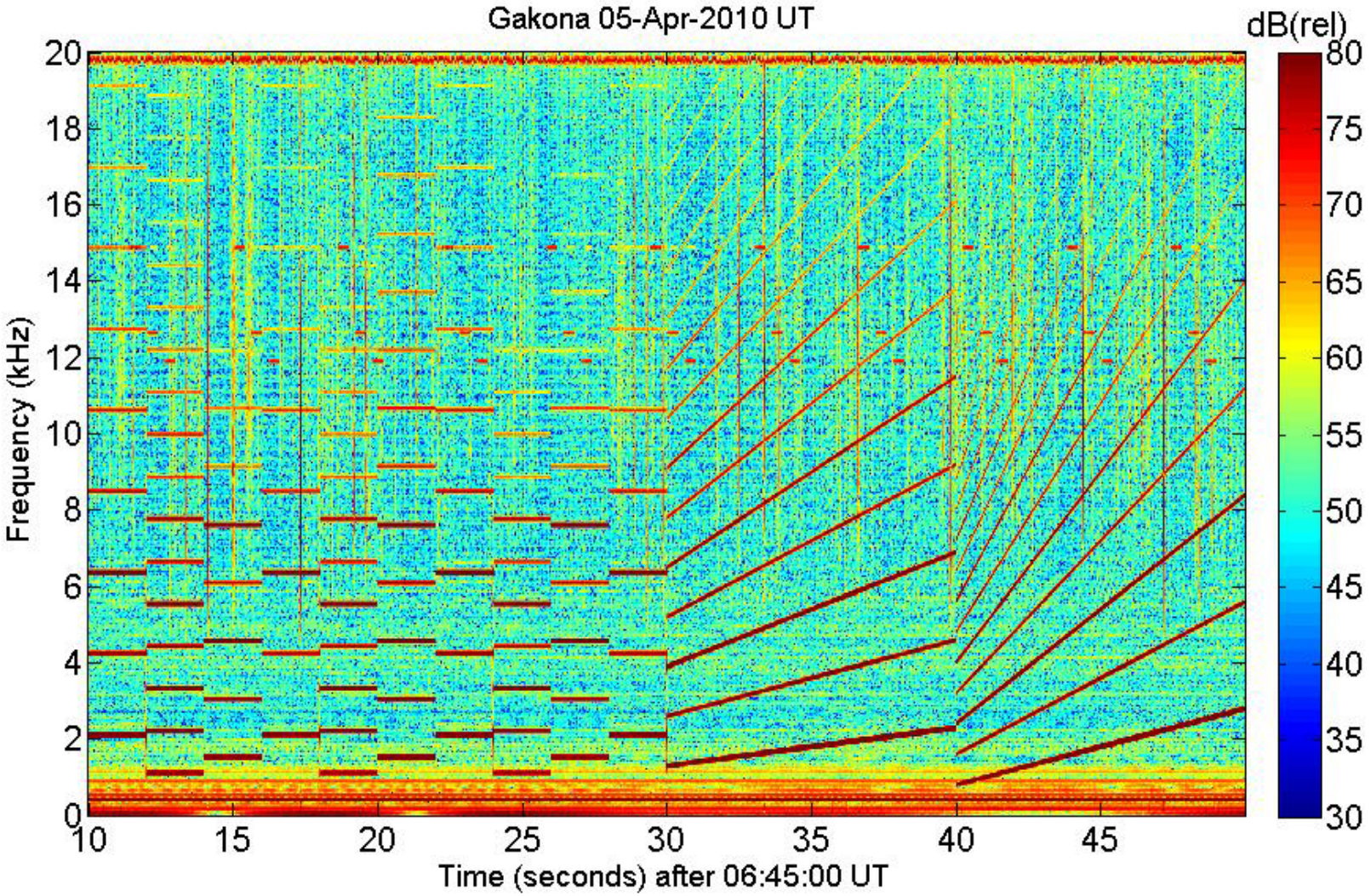


Hiss, chorus, echoes, same ionospheric exit point

HAARP Campaign: 4-15 Apr, 2010

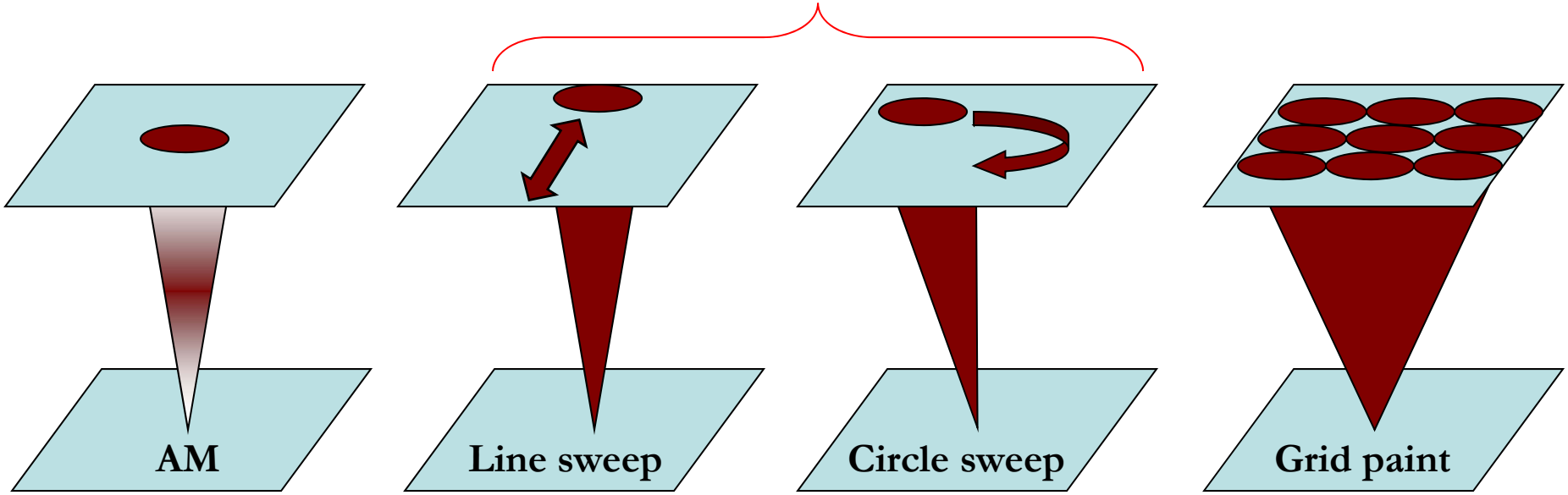


Very Strong ELF/VLF



Different Methods of Generation

Geometric Modulation:



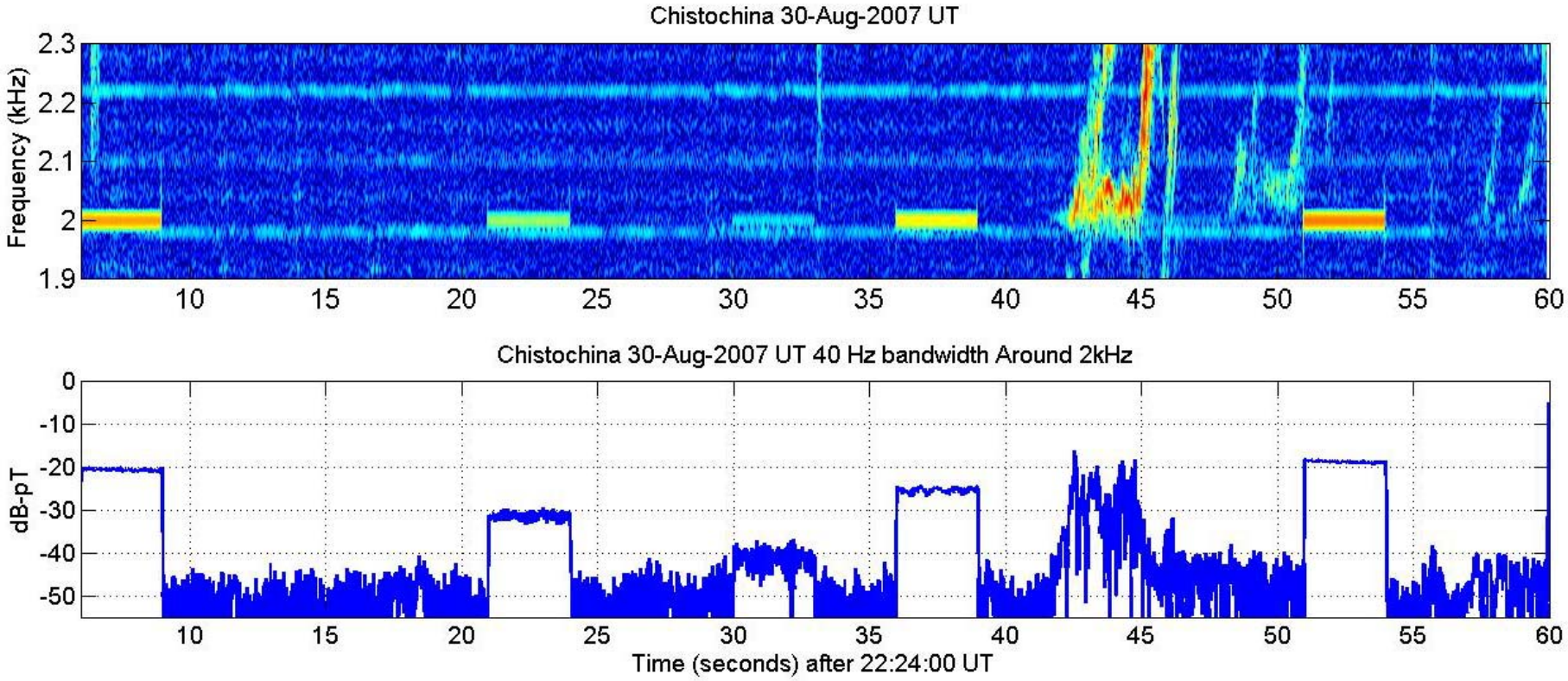
- Amplitude modulated signal
- 50% Duty cycle

- CW signal
- +- 15° line pattern
- ELF frequency dictated by line frequency

- CW signal
- Circular beam pattern
- ELF frequency dictated by spin frequency

- AM signal
- 3x3 grid, 10 μs dwell time at each point
- “Beam painting” technique

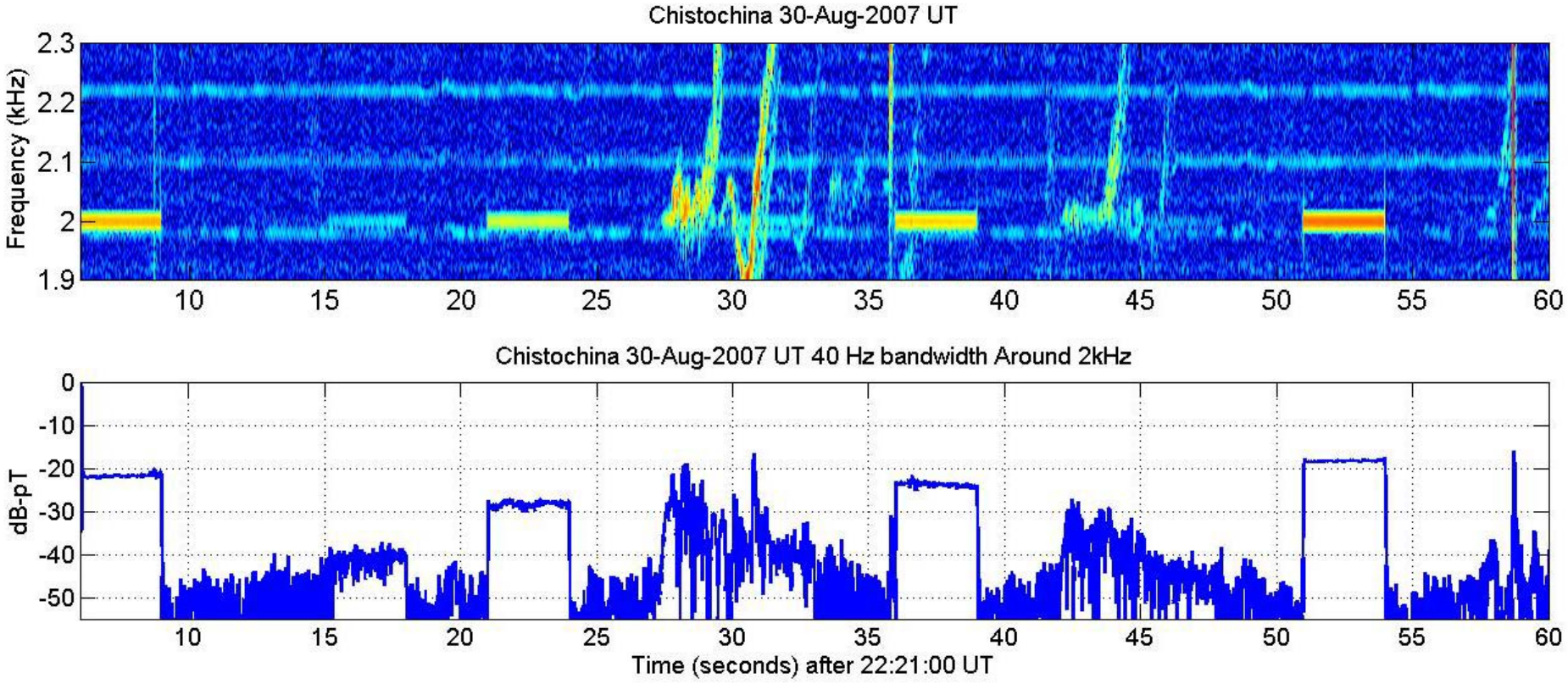
Different Methods of Generation



AM Modulation	Line Sweep	Circle Sweep	'Beam Paint'

- **Different methods of excitation yield different magnetospheric results**

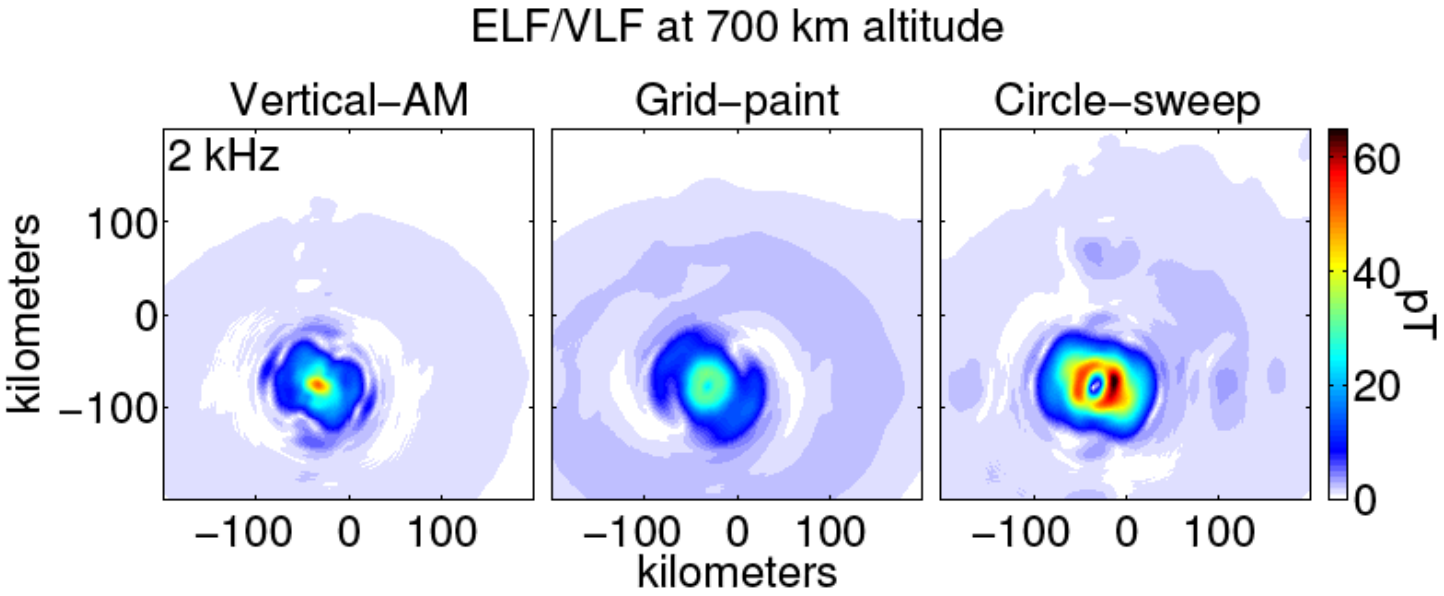
Different Methods of Generation

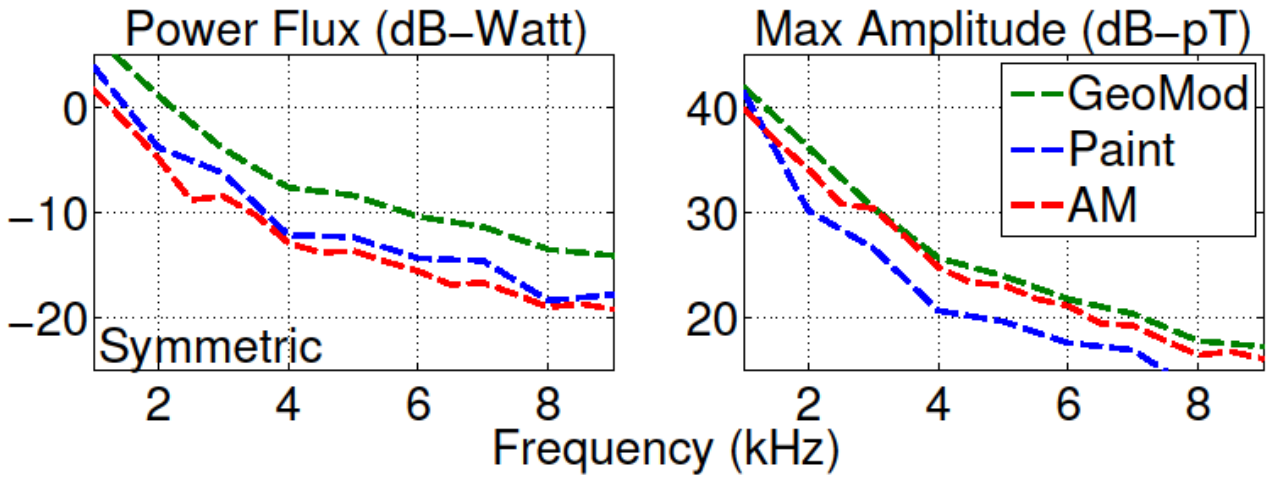


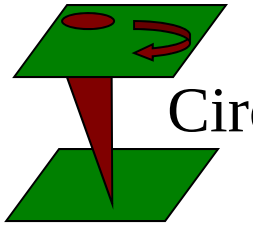
AM Modulation	Line Sweep	Circle Sweep	'Beam Paint'

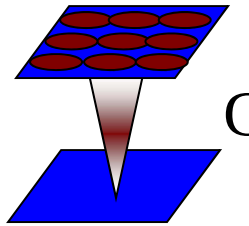
- **Sometimes the line sweep is better**

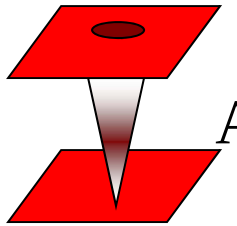
Magnetospheric Injection: Predictions











Summary/Conclusions

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Survey of geomagnetic indices indicates that observations occur during quieting/recovery following a disturbance

Multi-station ground observation shows evolution of natural emissions from hiss to chorus to HAARP induced amplification

Modeling shows that AM and Geometric Modulation yield highest wave amplitudes

References

J. Bortnik, R. M. Thorne, N. P. Meredith (2008), The unexpected origin of plasmaspheric hiss from discrete chorus emissions, *Nature,* 452, 62.

Carpenter, D. L., and Z. T. Bao (1983), Occurrence properties of ducted whistler-mode signals from the new VLF transmitter at Siple Station, Antarctica, *J. Geophys. Res*., 88, (A9), 7051-7057.

Koons, H. C. (1981), The role of hiss in magnetospheric chorus emissions, *J. Geophys. Res., 86*, 6745– 6754.

Omura Y., Y. Katoh, D. Summers (2008), Theory and simulation of the generation of whistler-mode chorus, *J. Geophys. Res.*, 113, A04223, doi:10.1029/2007JA012622.