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

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

Average Kp Values (via Ap)

- **Echo Observations (15)**
- **All Transmissions (297)**
- **Avg. 2007–2009**

Statistical Significance (2–Sample Kolmogorov–Smirnov Test)

- $p < 0.01$
- $0.01 < p < 0.03$
- $p > 0.03$
Geomagnetic Conditions: Kp

Disturbance 3-4 Days Before

Quieting/Recovery 12 Hours Before

Average Kp Values (via Ap)

Echo Observations (15)
All Transmissions (297)
Avg. 2007–2009

Statistical Significance (2-Sample Kolmogorov–Smirnov Test)

p-value

0
0.01
0.001

Days from Observation
Geomagnetic Conditions: AE

Average AE Values

- **Echo Observations (16)**
- **All Transmissions (279)**
- **Avg. 2007–2009**

Statistical Significance (2–Sample Kolmogorov–Smirnov Test)

- **p <0.01**
- **0.01 < p < 0.03**
- **p > 0.03**
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
Hiss transitions to chorus still no echoes
Two Hour Evolution: Echoes

Chorus gives way to 2-hop echoes of same amplitude
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: \textit{hiss} -> \textit{chorus}  
    \cite{KoonsetalJGR1981}?
  - Effect of propagation and dispersion: \textit{chorus} ->\textit{hiss}  
    \cite{BortniketalNature2008}?
  - Linear (hiss) versus non-linear (chorus, echoes) radiation of free energy from anisotropy of electron distribution  
    \cite{OmuraetalJGR2008}?

- Do observed emissions originate from the same place?
Multiple Site Measurements

- Dot Lake (151 km)
- Chistochina (37 km)
- Gakona (4 km)
- Valdez (145 km)

Frequency (kHz):
- Dot Lake
- Chistochina
- Gakona
- Valdez

Secs after 02:05:00 UT:
- Frequency (kHz)
- dB-pT

UC Denver Electrical Engineering
Source Location: Emissions

Hiss, chorus, echoes, same ionospheric exit point
HAARP Campaign: 4-15 Apr, 2010

Kp Index for Latest HAARP Campaign

Day in April

Kp Index
Very Strong ELF/VLF
Different Methods of Generation

- **AM**
  - Amplitude modulated signal
  - 50% Duty cycle

- **Line sweep**
  - CW signal
  - +/- 15° line pattern
  - ELF frequency dictated by line frequency

- **Circle sweep**
  - CW signal
  - Circular beam pattern
  - ELF frequency dictated by spin frequency

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

Geometric Modulation:
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

ELF/VLF at 700 km altitude

- Vertical-AM
- Grid-paint
- Circle-sweep

Power Flux (dB-Watt)

Max Amplitude (dB-pT)

Symmetric

Frequency (kHz)

HAARP Wave Injection
Summary/Conclusions

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


