



# **Ionospheric Current Drive (ICD)**

## **Implications to Naval Systems**

**Presentation to  
National Naval Responsibility (NNR)  
Underwater Communications  
Technical Panel**

**Dennis Papadopoulos  
University of Maryland  
College Park**

**Acknowledge:**

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**DARPA BRIOCHE Program-M. Goodman PM**

**C.L. Chang BAE Systems/AT**

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# ***Outline***

- **The physics and Experimental PoP for Using HF heaters to Drive AC Currents at the Ionospheric E-region (top of Earth-Ionosphere Waveguide) without the need of electrojets**
- **Scaling of the results with geomagnetic location of heater. Gain of more than 40 dB near the dip equator**
- **Potential of barge or shipboard based mobile HF heaters for Navy ELF applications**
- **Importance of new results to**
  - **Tactical and and strategic sub ELF communications**
  - **As an enhancer and back up of B-G laser concept**



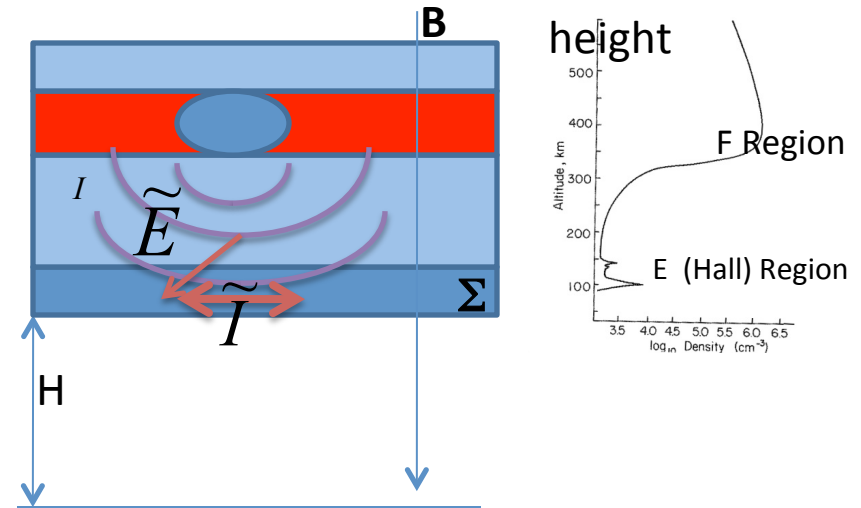
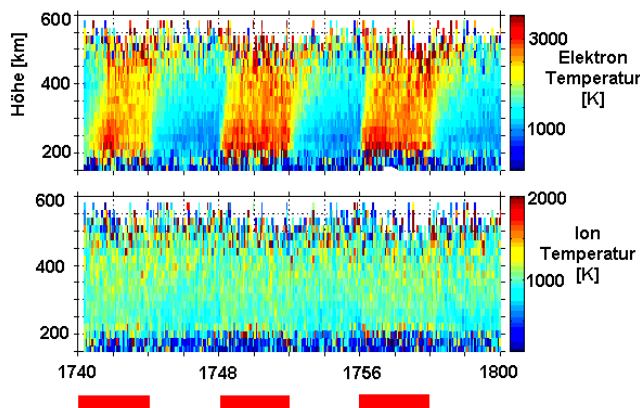
# What is New and why it is Important

**Challenge** – Use HF to drive an oscillatory current in the Hall Region without an electrojet

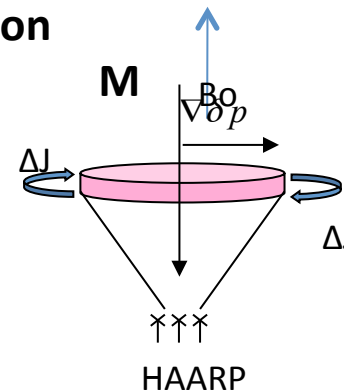
- Frees the system from location and PEJ variability problems
- Results in compact possibly mobile system

**New Concept: IONOSPHERIC CURRENT DRIVE (ICD)**

1. Use modulated HF to modulate the electron pressure in the F-region



2. Plasma Expansion creates a diamagnetic current that radiates MS waves, whose oscillatory electric field drives an oscillatory current in the E region

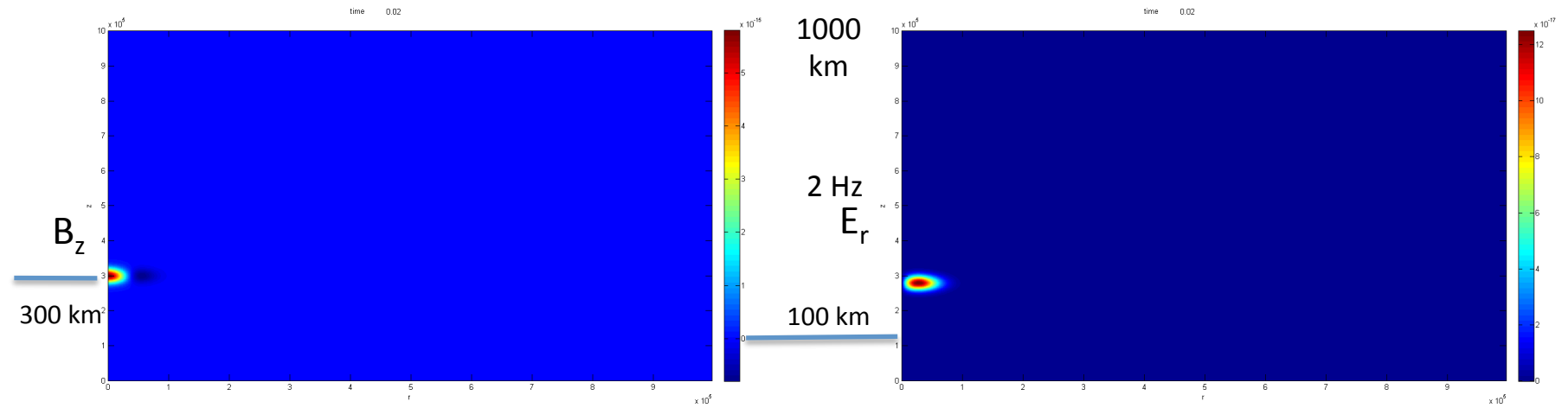


3. A secondary antenna is created on the top of the EIW

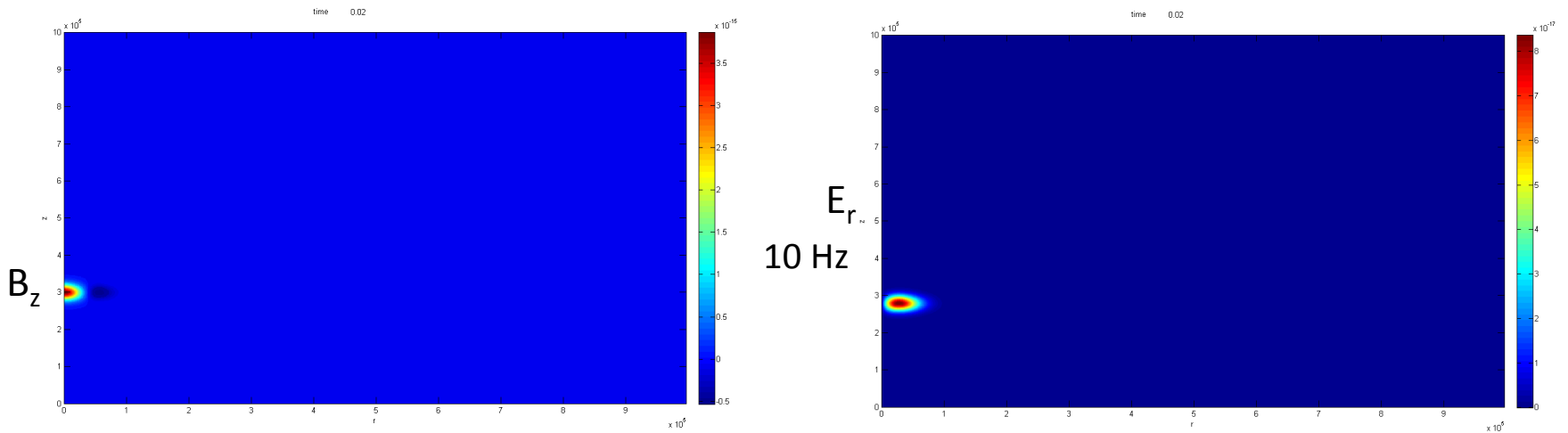
$$M_{top} \approx \tilde{I}LH$$

$$I \propto \Sigma \tilde{E}$$

# ICD Modeling

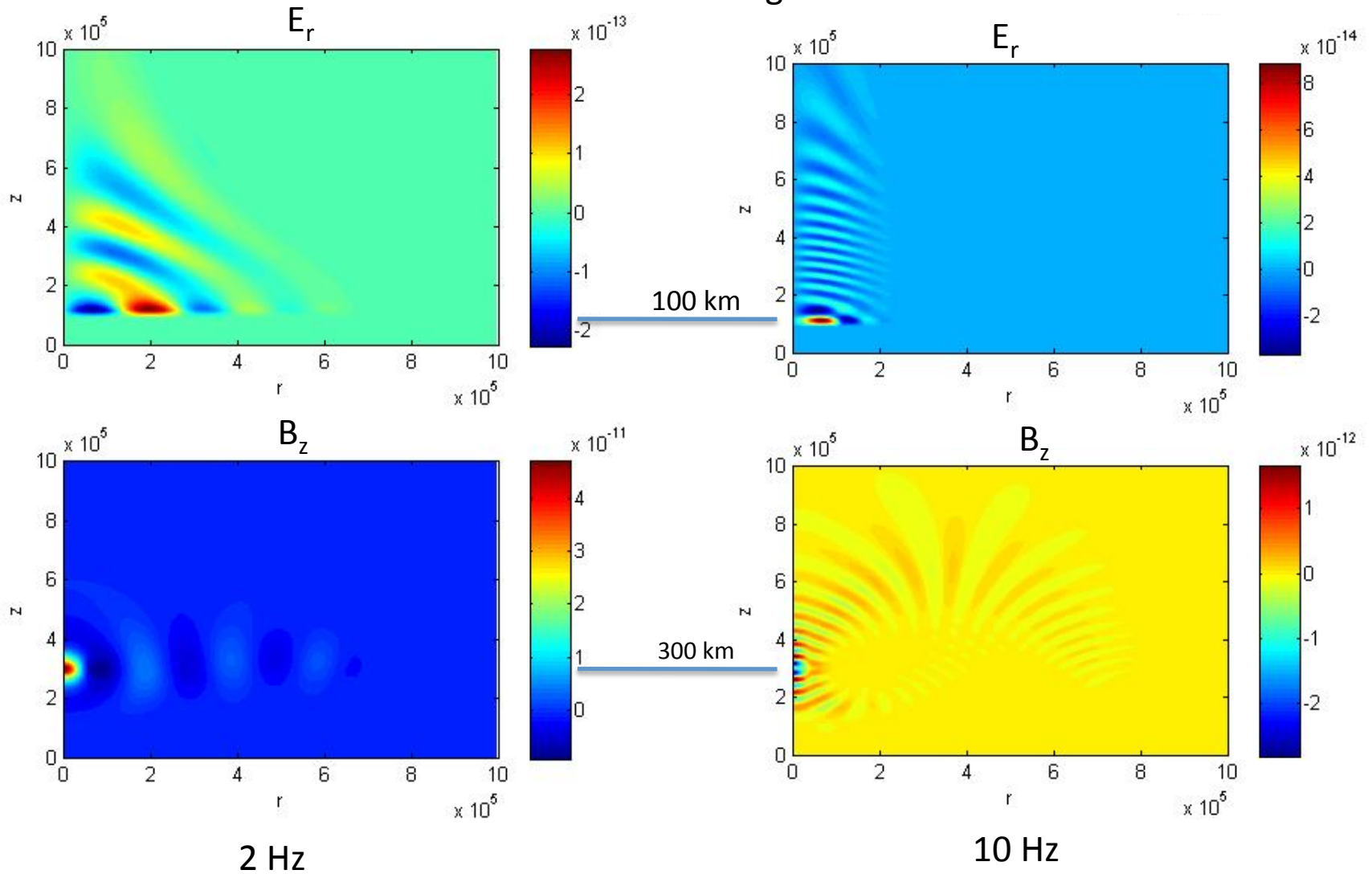


1000 km



# ICD Modeling

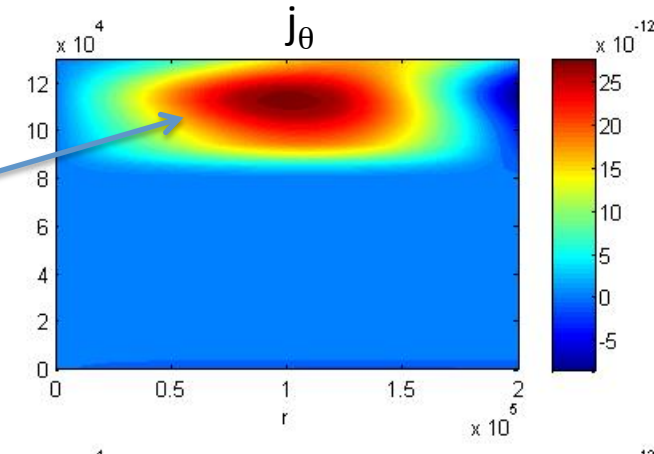
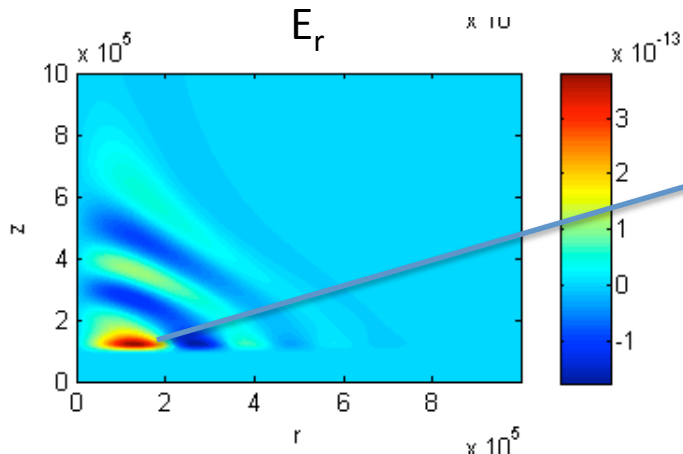
1000x1000 km grid



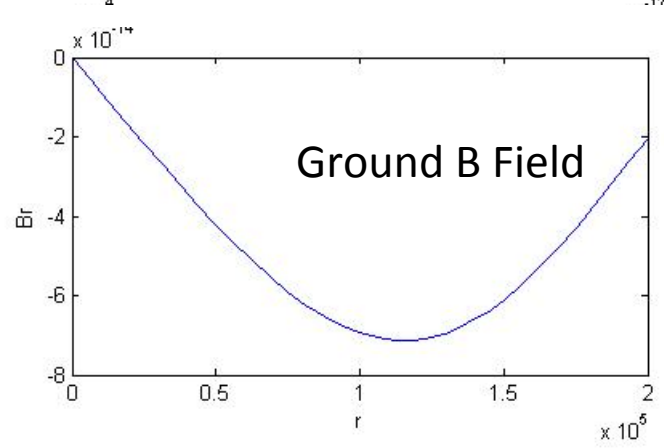
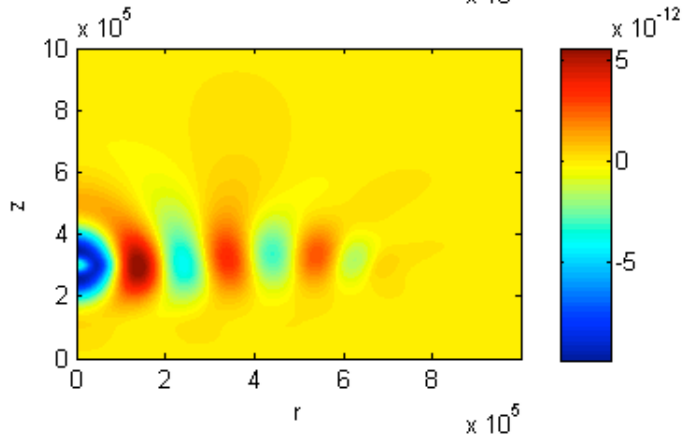


# ICD Modeling – Fields on the ground

## 2 Hz



E- region current  
 $J_\theta$

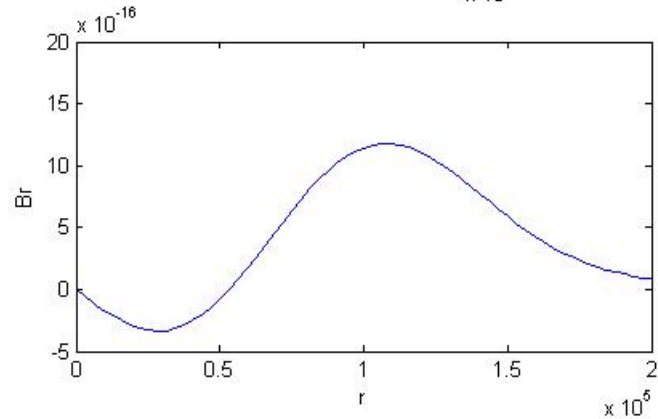
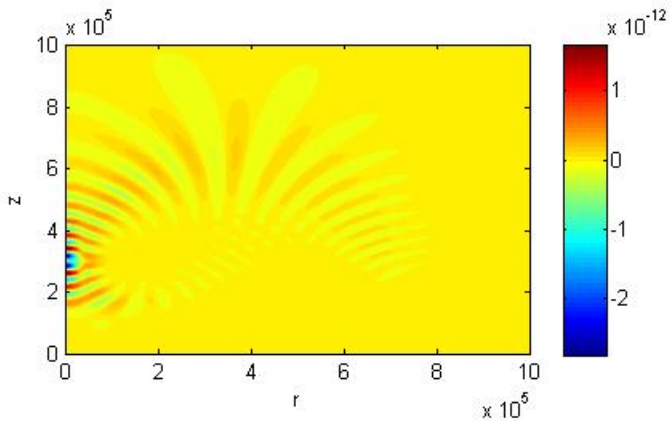
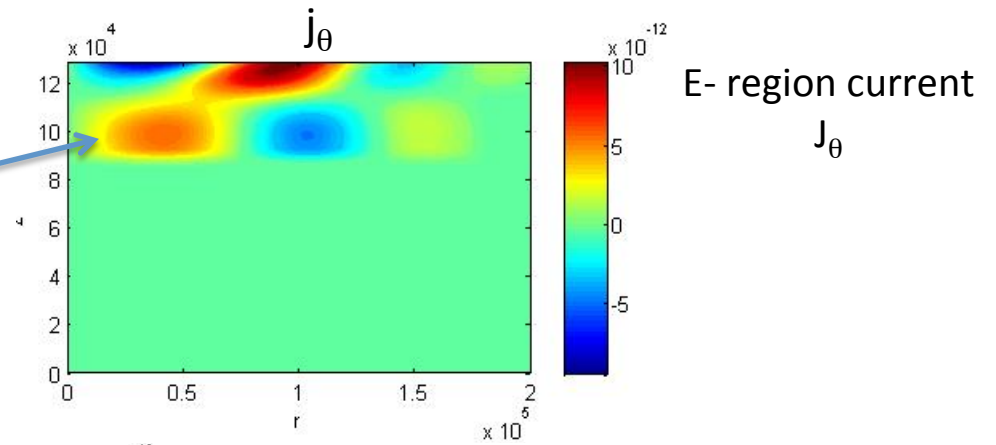
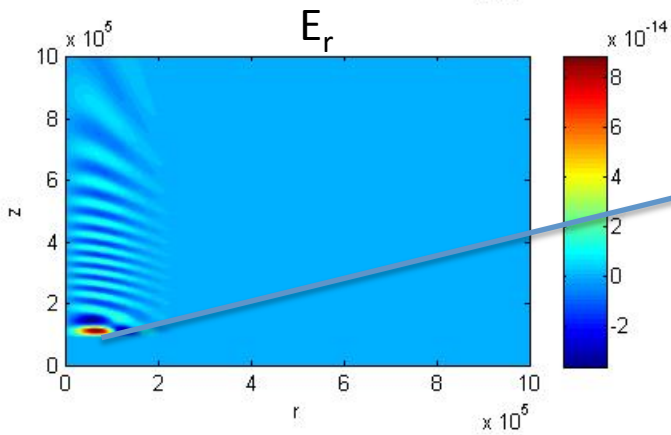


$B_r$  field on  
the ground  
Near field



# ICD Modeling – Fields on the ground

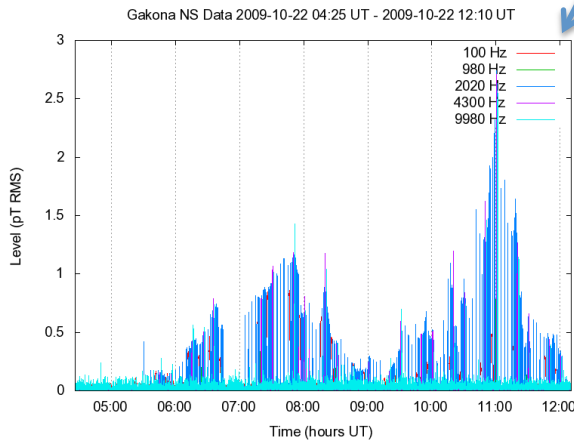
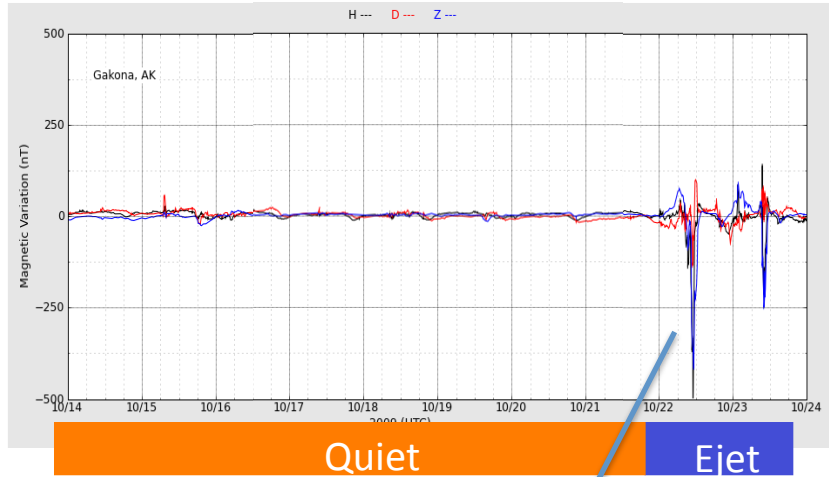
## 10 Hz



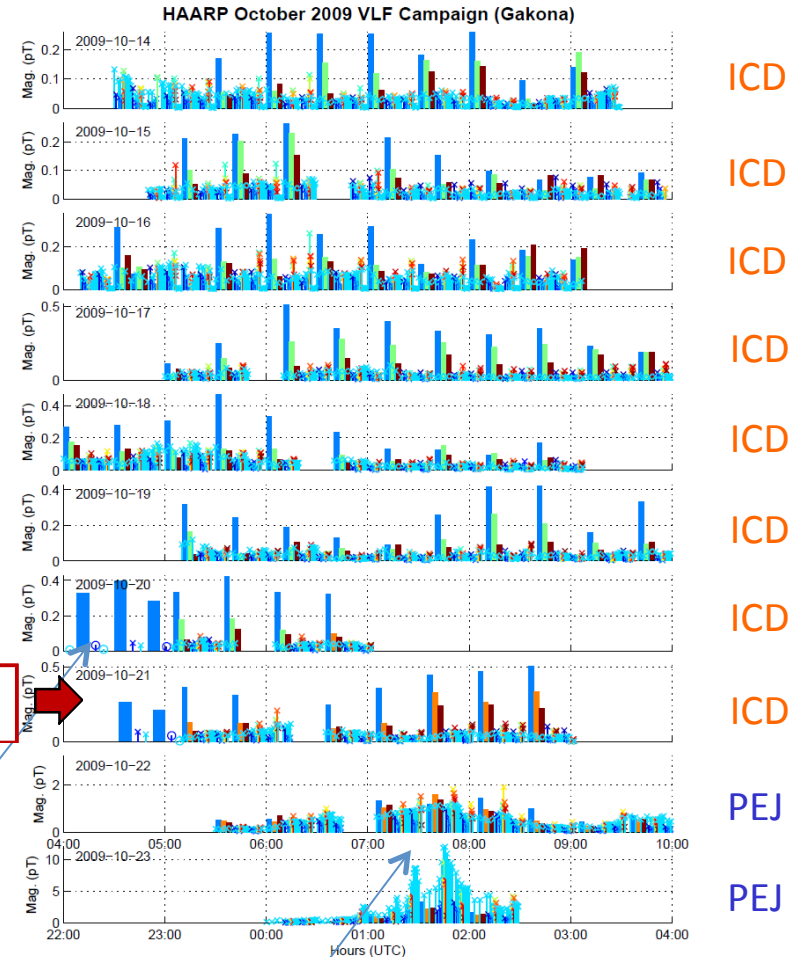
B field on the ground  
Near field



# PoP ICD Generation - ICD vs. PEJ



**ULF-ELF (12-49 Hz) Thick Bars**  
**ELF-VLF (500-8K Hz) Thin Lines**

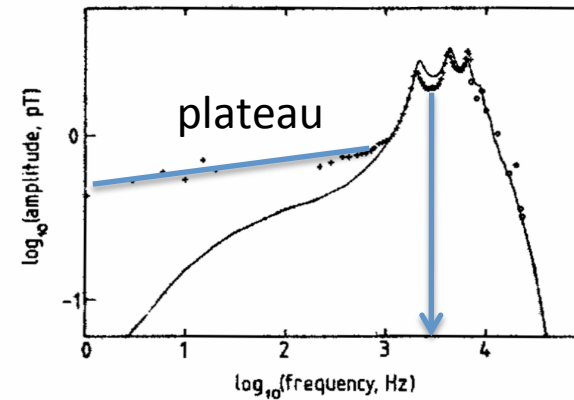
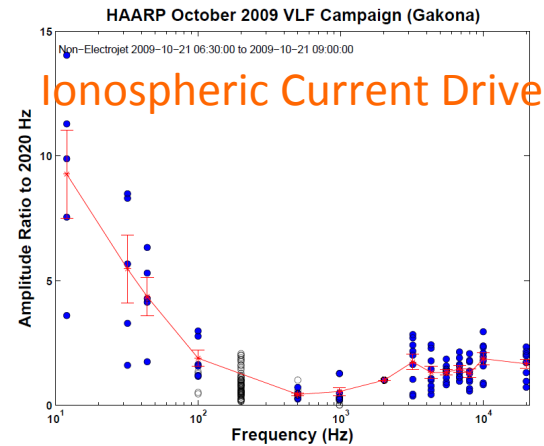


2 kHz amplitude on the ground  
 Indicator of Electrojet strength  
 06:00-12:00 UT, 10/22/09

- 12 Hz
- 28 Hz
- 32 Hz
- 44 Hz
- 100 Hz
- 200 Hz
- 500 Hz
- 980 Hz
- 2020 Hz
- 3200 Hz
- 4000 Hz
- 4300 Hz
- 5500 Hz
- 6000 Hz
- 6800 Hz
- 8000 Hz
- 9980 Hz
- 20000 Hz

# ICD vs. PEJ Frequency Scaling

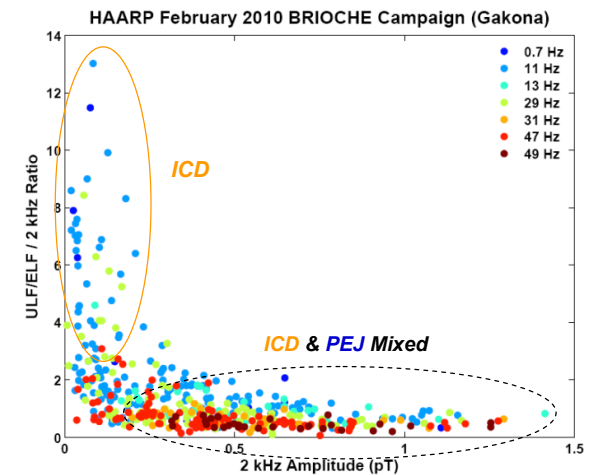
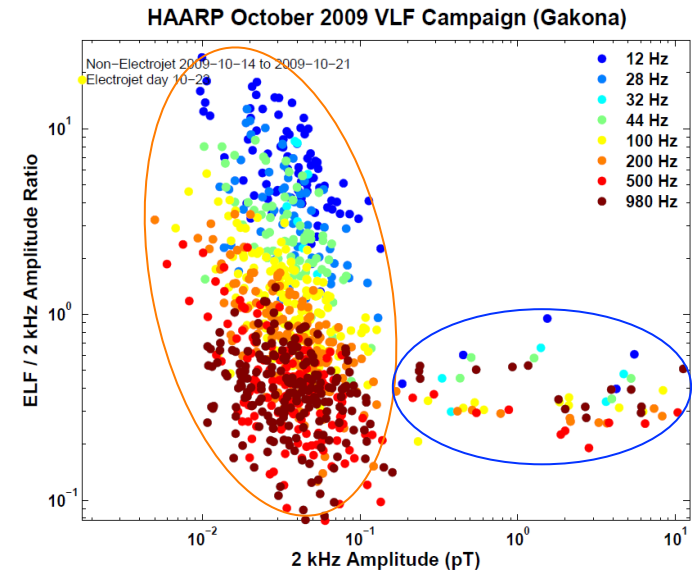
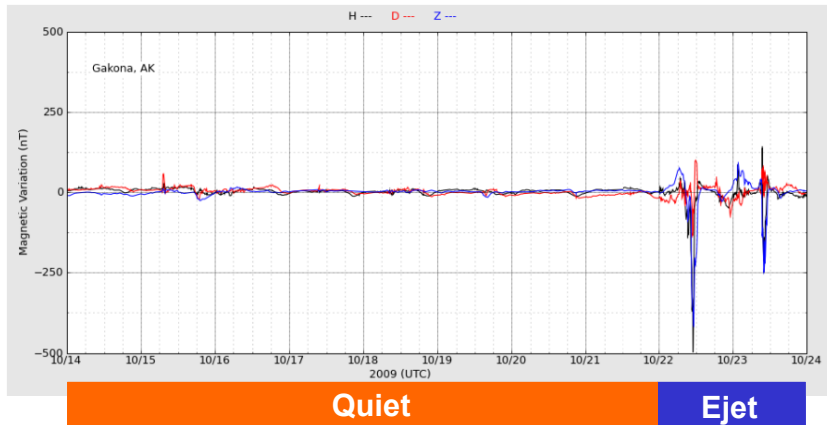
- Ionospheric current drive (**ICD**) produced ELF waves up to 50 Hz
  - F layer mod. - No electrojet
  - < 50 Hz,  $1/f^\alpha$  dependence
    - Consistent ELF source suitable for mid/low latitude regions
    - Upper freq. is limited by pressure relaxation time scale of the F layer
- Polar electrojet modulation (**PEJ**) produced ULF/ELF/VLF waves 0.1Hz -20 kHz
  - D/E layers mod. - With electrojet
    - < 1 kHz: plateau
    - 2-8 kHz: peak efficiency
    - > 10 kHz:  $1/f^\alpha$  decrease



PEJ

# Overall ELF/VLF Results

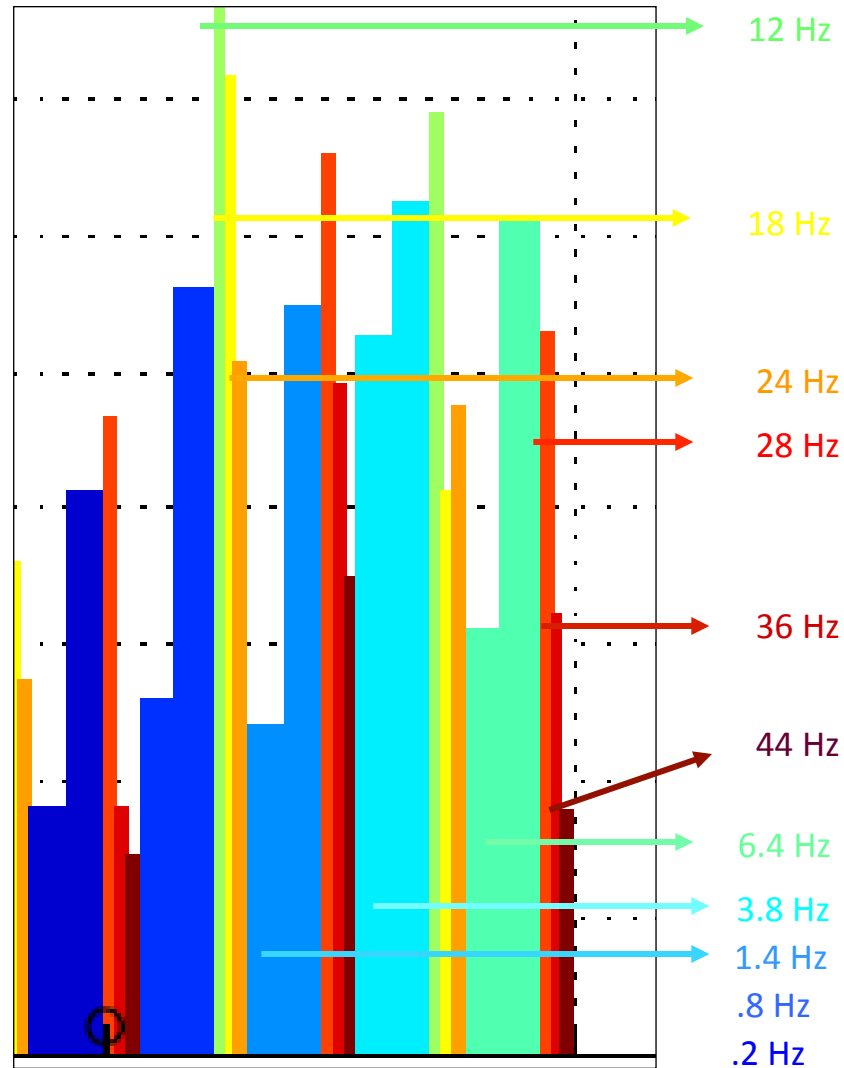
- 10 Hz – 1 kHz Gakona results
  - Normalized to 2 kHz amp.
- Two distinct groups of data
  - Quiet time
  - During Electrojet





# Scaling with Frequency and Power

$B \sim P_{HF}$   
 $B \sim 1/f, f > 12 \text{ Hz}$

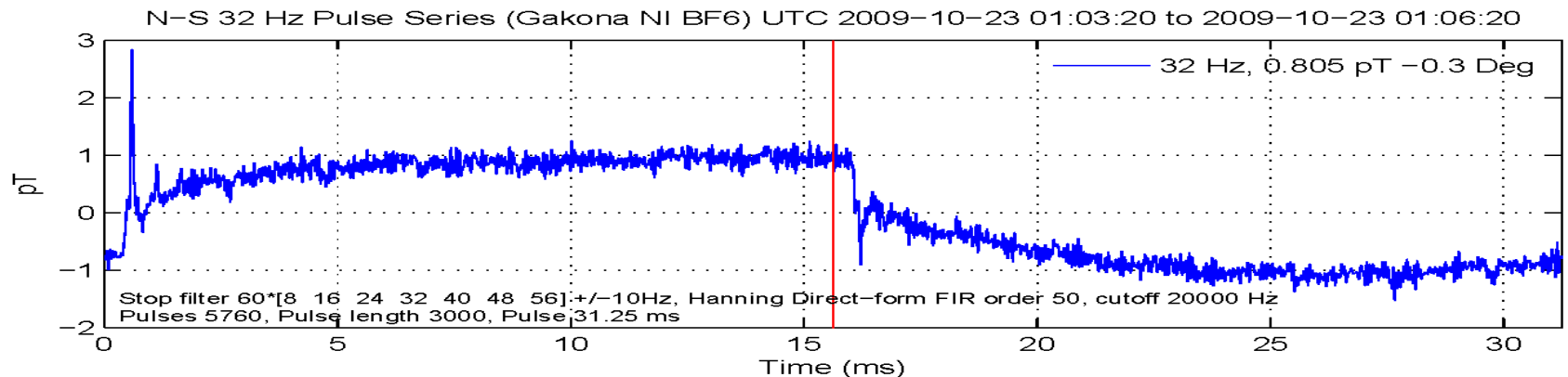
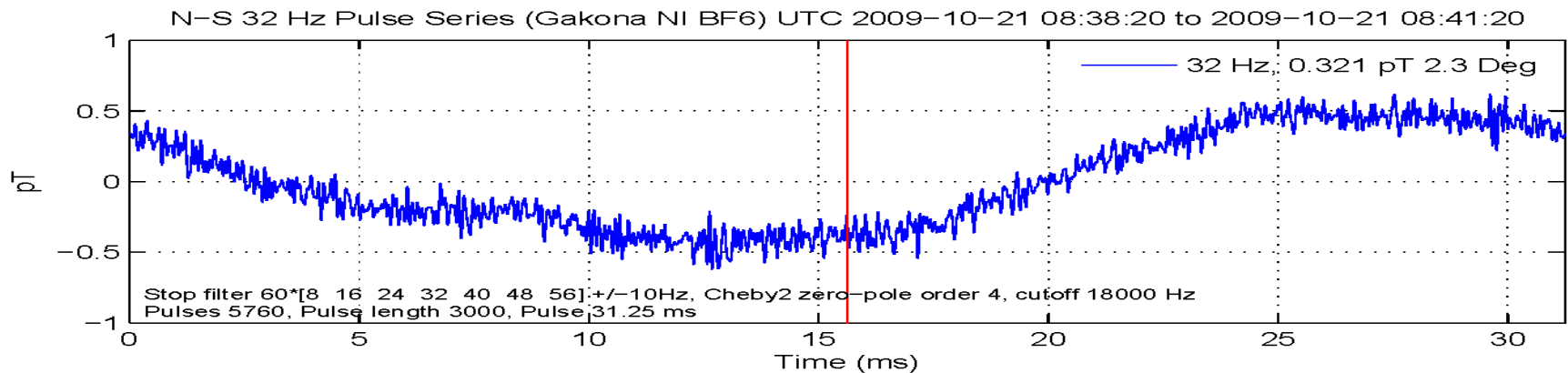




# ICD vs. PEJ Waveform Comparison

E vs. F relaxation time difference

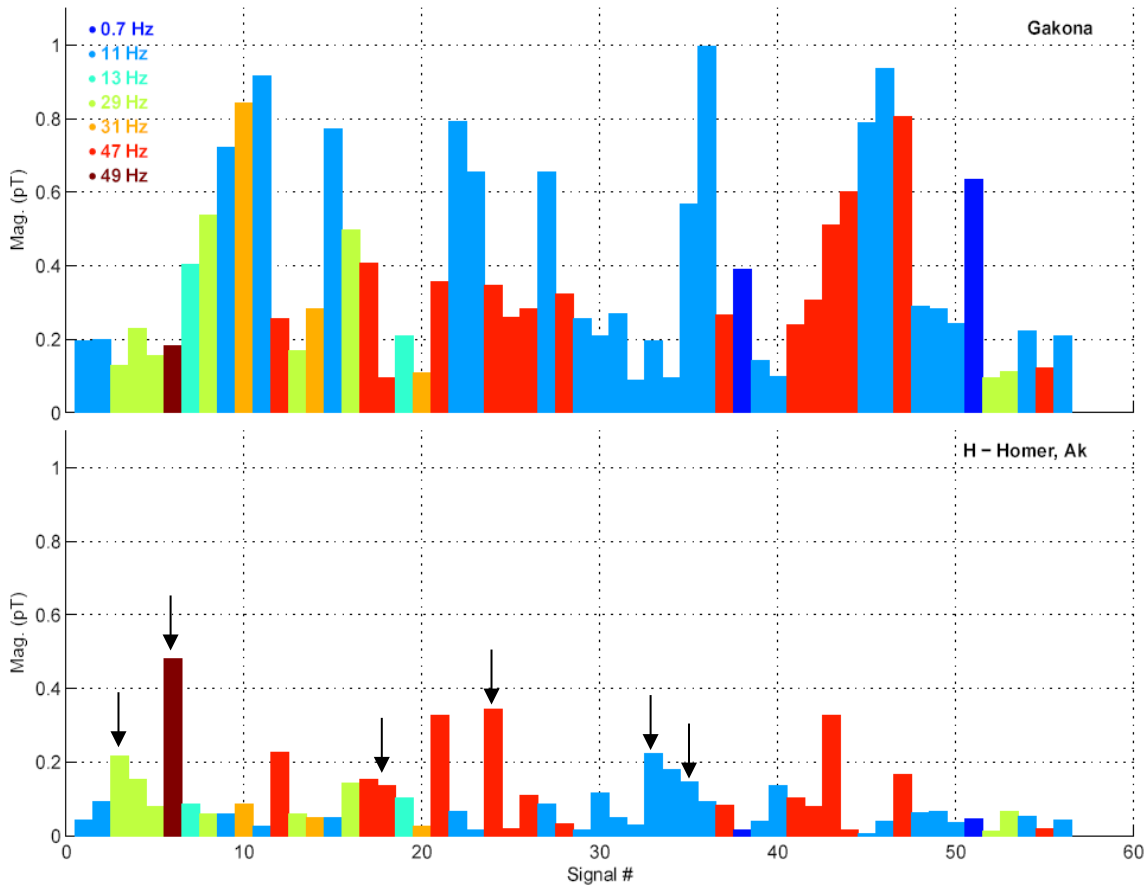
F Layer ICD



D/E Layer PEJ

# ELF Measurements at Homer (300 km)

HAARP February 2010 BRIOCHE Campaign

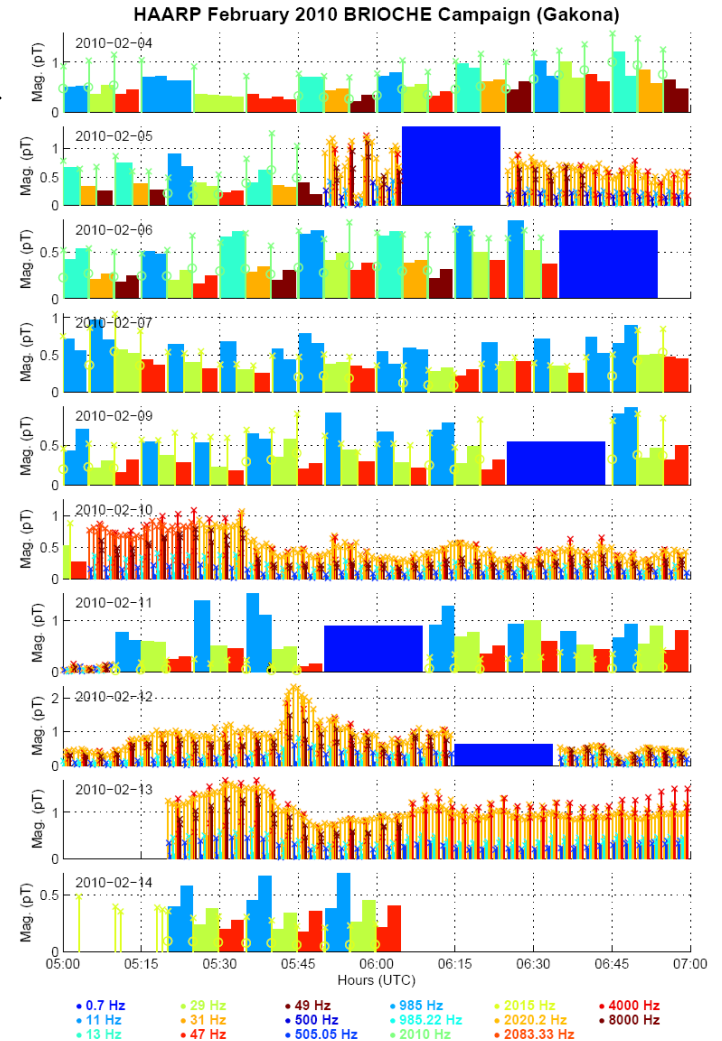


# Summary: Ionospheric ELF Source Without Electrojet

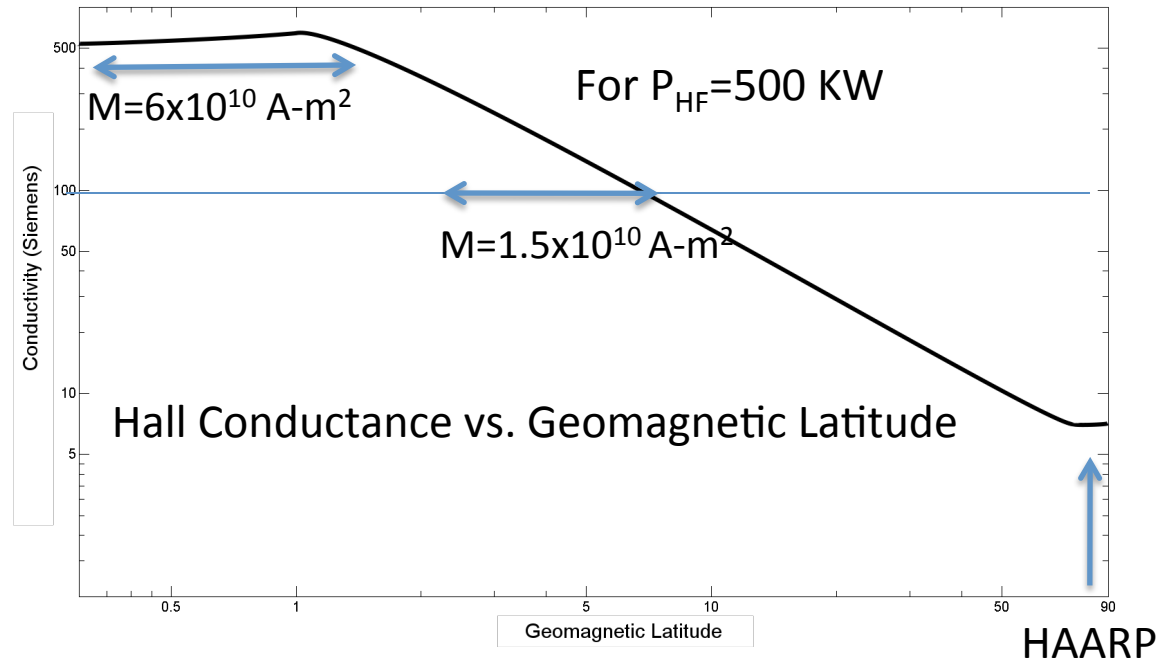
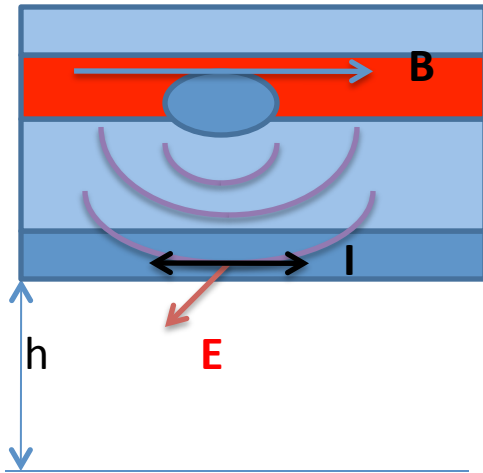
ULF-ELF (0.7-49 Hz) Thick Bars  
 ELF-VLF (500-8K Hz) Thin Lines



- ELF produced by HAARP with **NO Electrojet** – **A Major Breakthrough**
  - Predictable and repeatable ELF generation up to 50 Hz on daily basis
  - $M_{\text{eff}} \approx 5 \times 10^9 \text{ A}\cdot\text{m}^2$
  - $M_{\text{eff}} \sim P_{\text{HF}}$
  - Validated technique: plasma currents driven by HF heating in the F/E layers
  - Technology transferable to low latitude regions with robust F & no Electrojet



# ICD Scaling with Geomagnetic Latitude



$$M_{eff} \approx ILh \approx (\Sigma EL)Lh$$

$$M_{eff}(\lambda) \approx (5 \times 10^9) \left[ \frac{\Sigma(\lambda)}{5S} \right] \left( \frac{P_{HF}}{3.6MW} \right) A - m^2 \approx$$

$$\approx (2.7 \times 10^8) \Sigma(\lambda) (P_{HF} / MW) A - m^2$$

For  $P_{HF}=500$  kW we get

$$M_{eff} \approx 6 \times 10^{10} \text{ A-m}^2 \text{ at } \lambda \approx 0$$

$$M_{eff} \approx 1.5 \times 10^{10} \text{ A-m}^2 \text{ at } \lambda \approx 6^\circ$$



# Implications - Barge or Shipboard Option

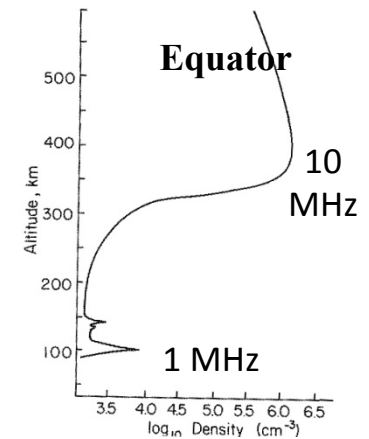
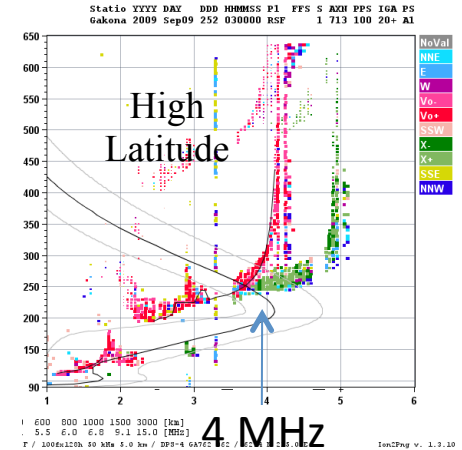
Combination of low HF power and high HF frequency requirements allow for mobile option



Strawman HF Array

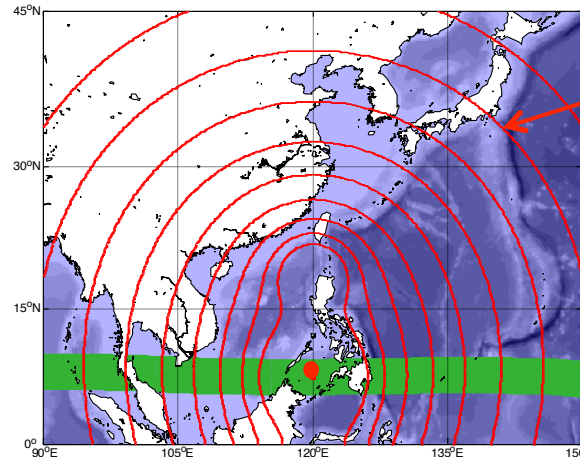
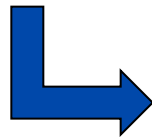
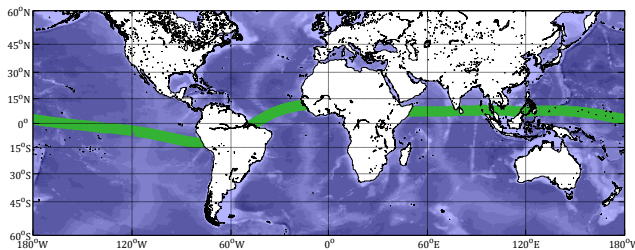
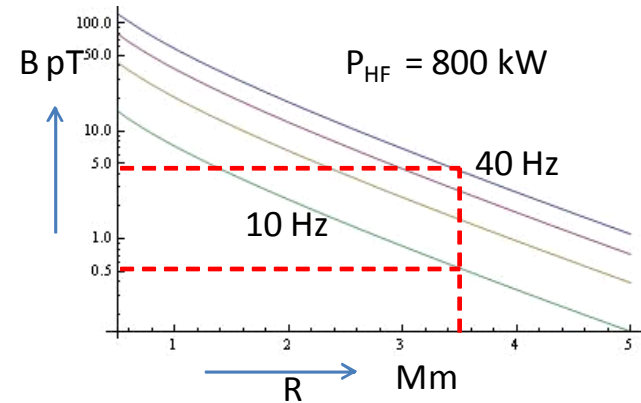
- HF frequency 8-10 MHz
- Linear polarization
- Twenty 25-kW solid state transmitters
- Ship provided power

- Can provide theater and strategic sub communications
- Enhance Blue-Green laser tactical communications by providing info as to transmit and receive locations



# ELF Mobile Array Performance

- Optimal area for Mobile Array along Magnetic Equator (green band, within 2° from dip equator )
- Power requirements depend on location
  - Example: Korea - Yellow Sea
    - 800 KW system can provide data rates in the tens of bit/sec
    - Signal as large as 5 pT at 40 Hz or more at range of 3500 km
    - Typical background noise at 40-80 Hz is 200-500 fT/Hz<sup>1/2</sup>



800 kW HF System  
5 pT line at 40 Hz

Optimal Region  
For ELF Array



## *Summary of equatorial location advantages*

- **Equatorial ionosphere much more reliable than auroral**
- **Equatorial electron density profiles better suited to heating at high altitudes (improving heating efficiency and reducing absorption)**
- **Cowling current provides a factor of 100 more ELF power than aurora for similar VMD moment**
- **Equatorial heating creates significant vertical electric dipole moment providing isotropic coverage**
- **Equatorial and sea based facilities can provide global ULF/ELF coverage for all frequencies up to 50 Hz**
- **Required HF frequency 6-10 MHz. Facility smaller and relatively inexpensive**



# *What is the Next Step*

## **VERIFY EXPERIMENTALLY SCALING WITH GEOMAGNETIC LATITUDE**

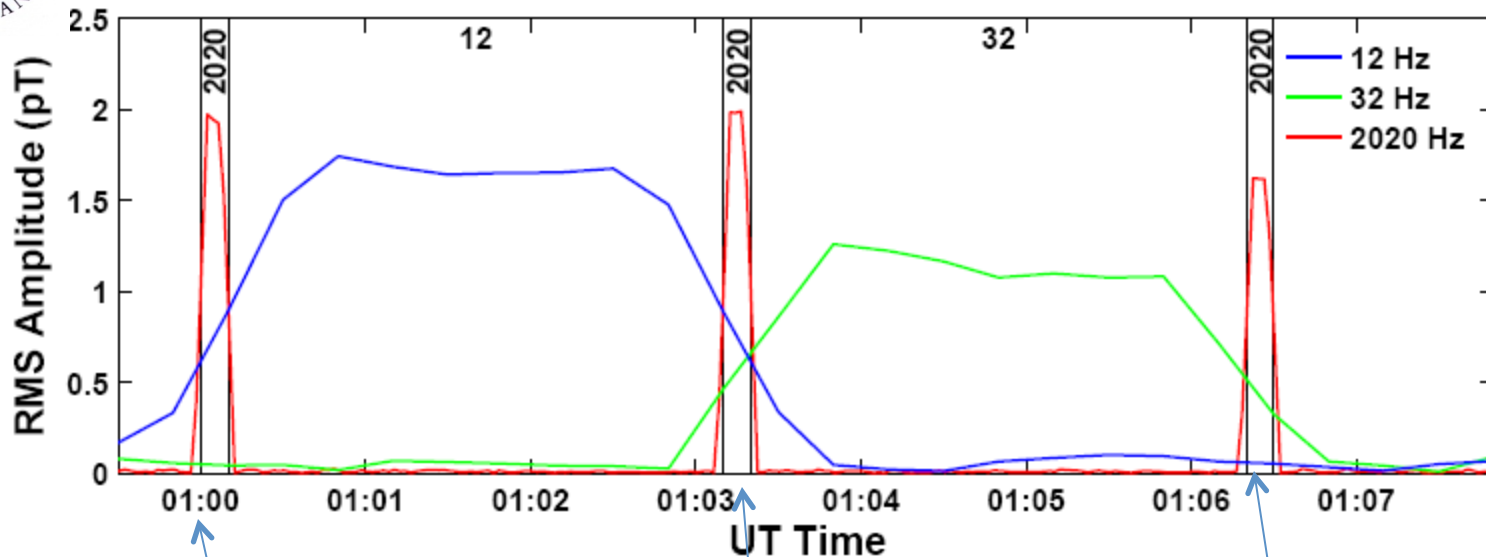
- Design a simple low-cost RF transmitting system ( $\sim 200\text{-}300$  KW) at 6-10 MHz
  - Options
    1. Use existing GFE equipment from OTH-B surplus: antenna, transmitters, cooling system, ground screen ... etc
    2. Re-design with solid state technology – Modular design for ease in relocation
- Select Equatorial Test Location
  1. Jicamarca Peru – Operated by Cornell for NSF – Complete diagnostic instrumentation and infrastructure –Joint ONR/NSF operation
  2. Explore US sites such as Guam

# **Supplementary Slides**



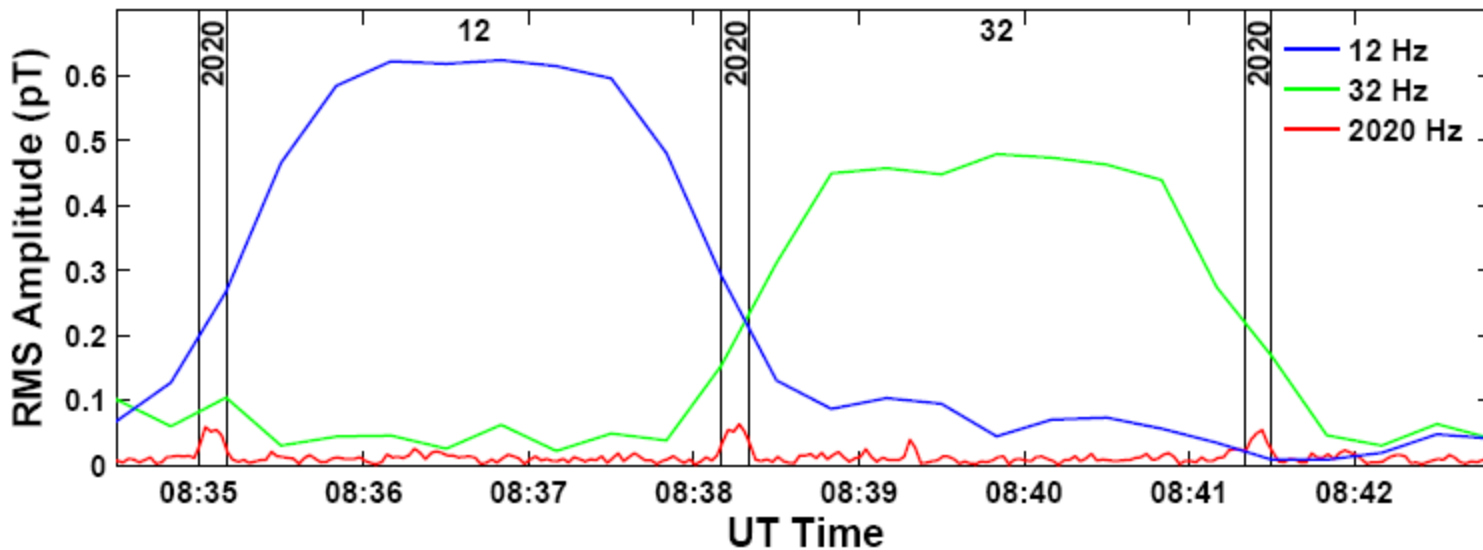
# PEJ

## HAARP B-Field Demodulation at 12, 32, 2020 Hz, 2009-10-23 UT



# ICD

## HAARP B-Field Demodulation at 12, 32, 2020 Hz, 2009-10-21 UT





# HAARP

