On the Viability and Requirements of a Barge Based ELF System

Presentation to Dr. Bobby Junker
ONR Code 31

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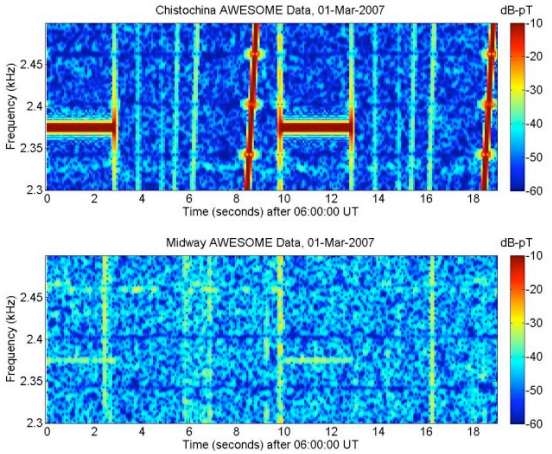
Outline

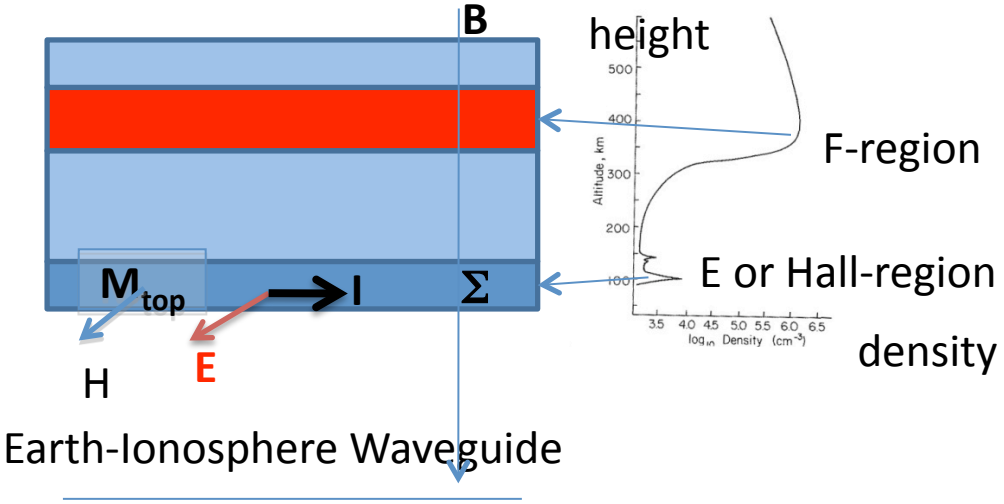
- The Physics and Experimental PoP for Using HF heaters to Drive AC Currents at the Ionospheric E-region (top of Earth-Ionosphere Waveguide) without the need of ejets
- Scaling of the results with geomagnetic location of heater. Gain of more than 40 dB near the dip equator
- Possibility of barge or shipboard based mobile HF heaters
- Importance of new results to
  - Tactical and Strategic sub ELF communications

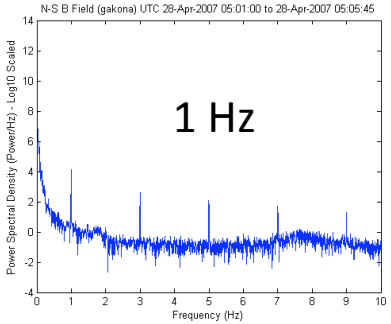
Q. Can we use ground HF to generate ELF at all times and provide strategic and tactical communications to submarines?

Current Status: Need the presence of an electrojet – Polar Electrojet (PEJ) Ant.



2.3 kHz Midway 4.5 Mm





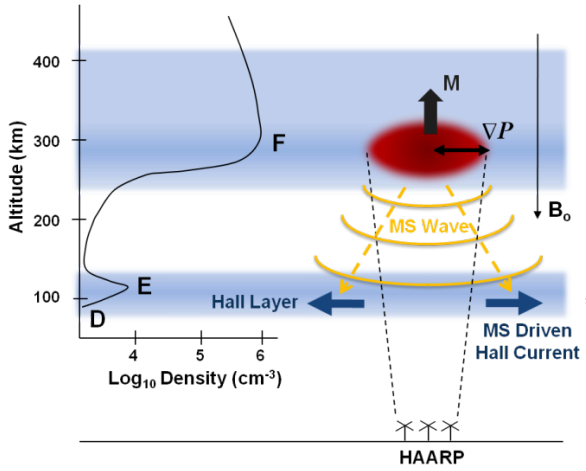
Ejet current $I \sim \Sigma E$

Modulate HF at ELF frequencies to get $M_{top} \sim (\Delta\Sigma)ELh$ at the mod. freq.

Problem:Polar Ejet current highly variable, far from relevant regions

Q: Can we use ground HF to generate ELF at all times and provide strategic and tactical communications to submarines?

MURI/BRIOCHE Challenge: Generate ELF using HF without needing an electrojet



Ionospheric Current Drive (ICD) Concept

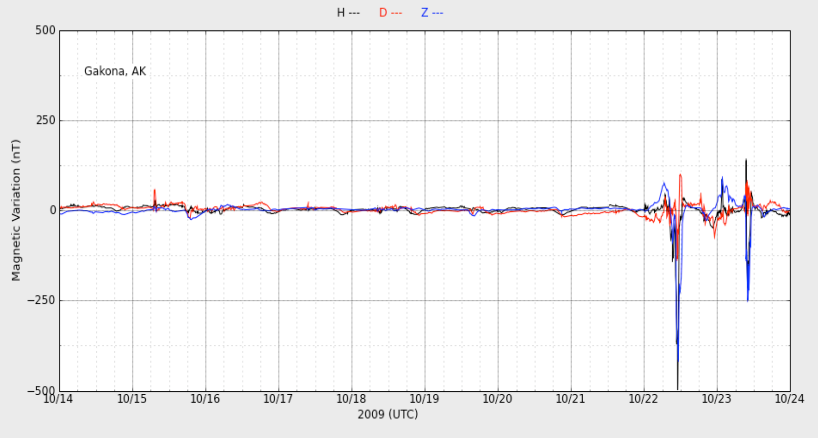
Step 1: $\Delta J = \frac{B \times \nabla \delta p}{B^2} \exp(i\omega t)$ → **MS Wave**

Step 2:

← E field of MS wave drives Hall current in E-region resulting in secondary antenna resembling PEJ

→ Injects SAW upwards and ELF in the Earth-Ionosphere Waveguide

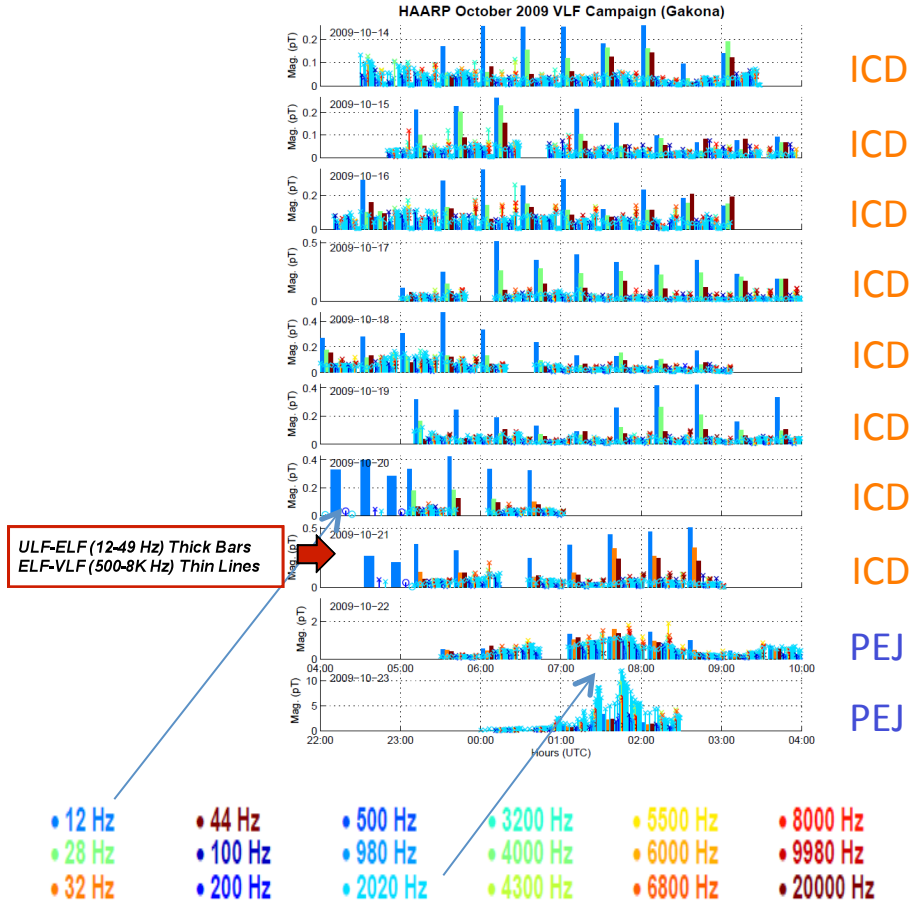
ICD Experimental Proof-of-Principle



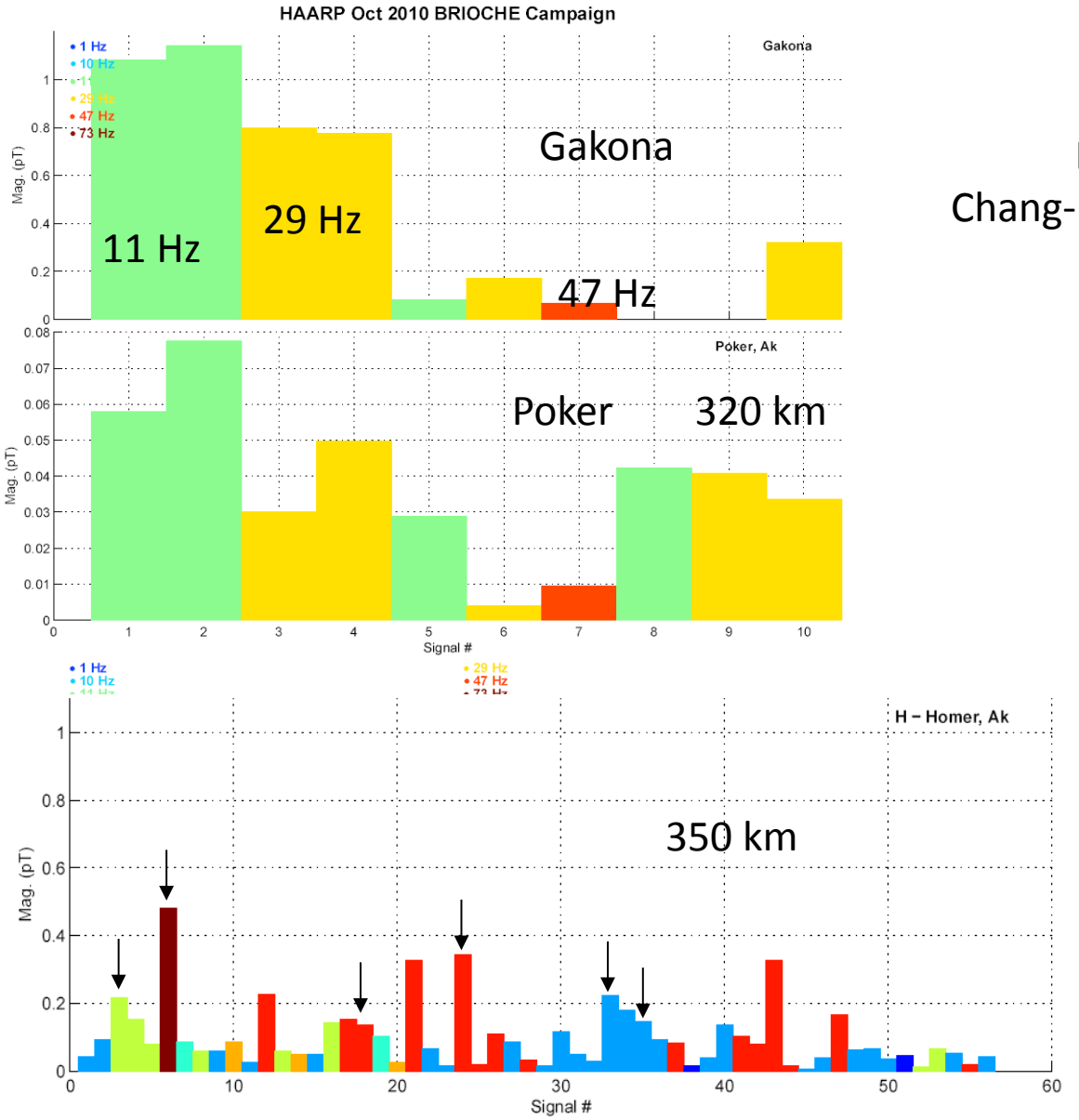
Quiet | Ejet

$M \approx 4 \times 10^9$ A-m^2

Results of DARPA/BRIOCHE Campaign
Chang- Papadopoulos



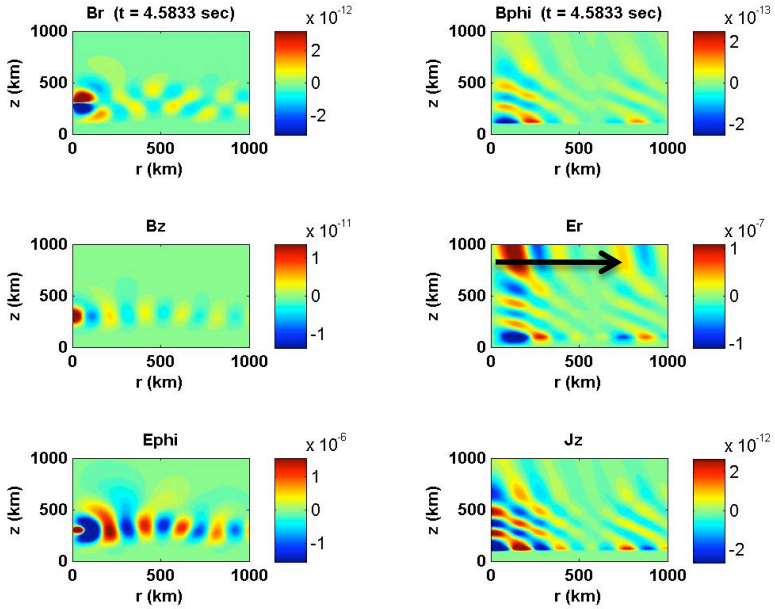
Far Site Measurements

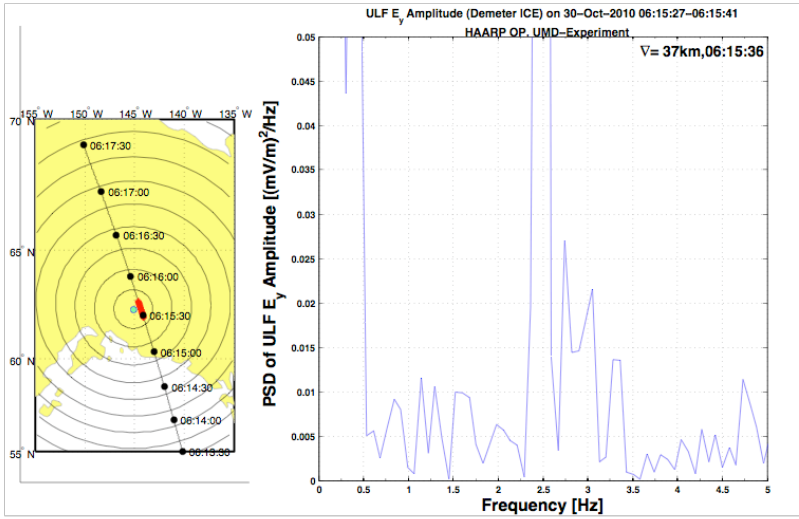


Results from
DARPA/BRIOCHE
Chang-Papadopoulos-Lebinsky

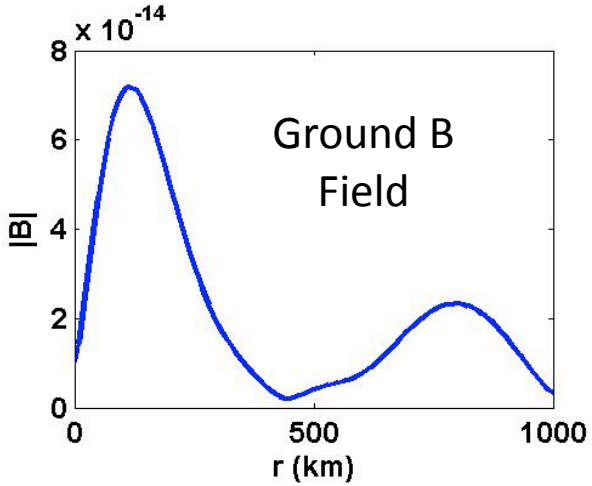
Model Validation

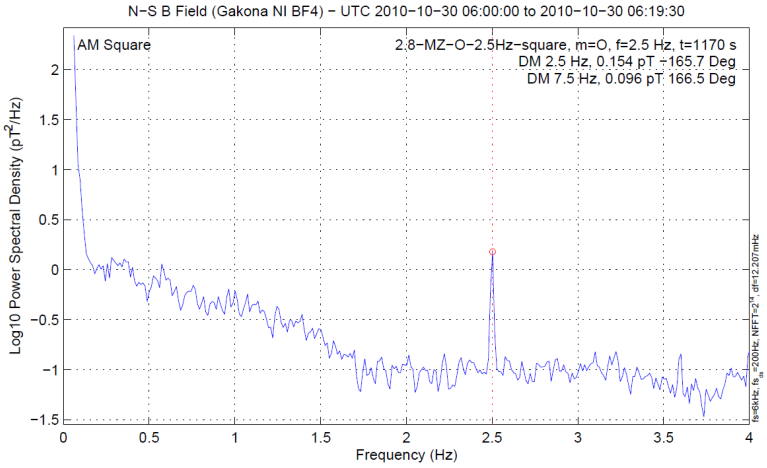
MURI/BRIOCHE Collaboration





MS t=4.6 sec SAW



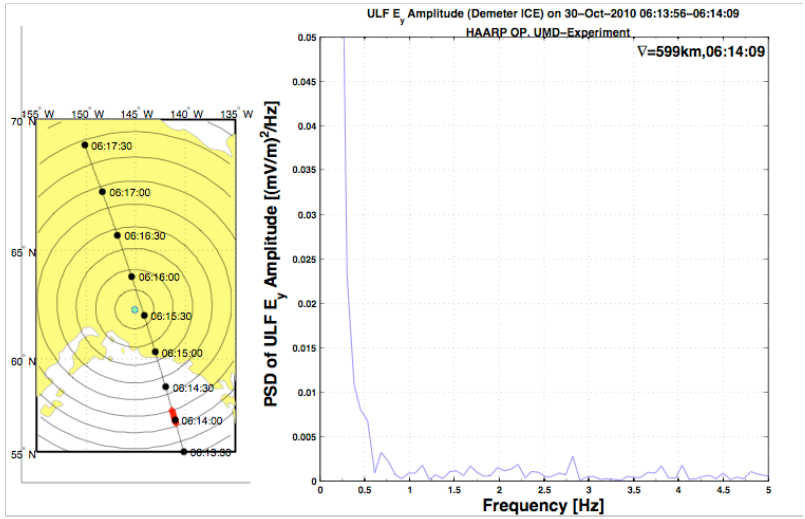


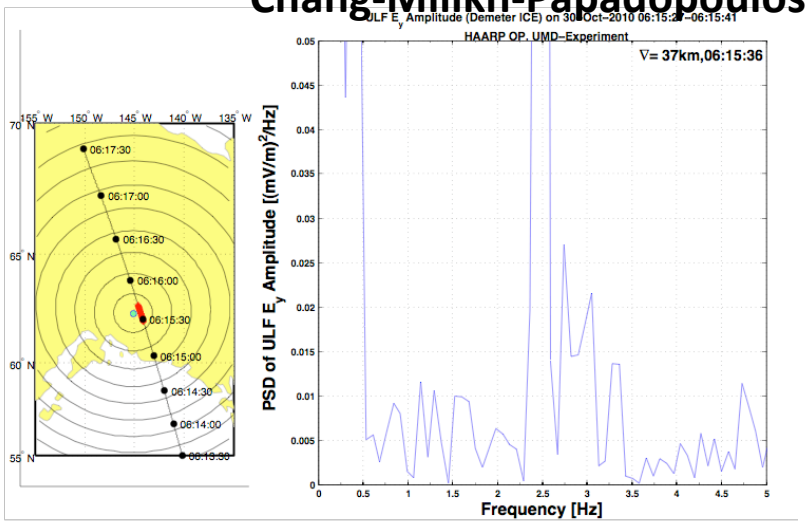
Model Validation -Field Confinement

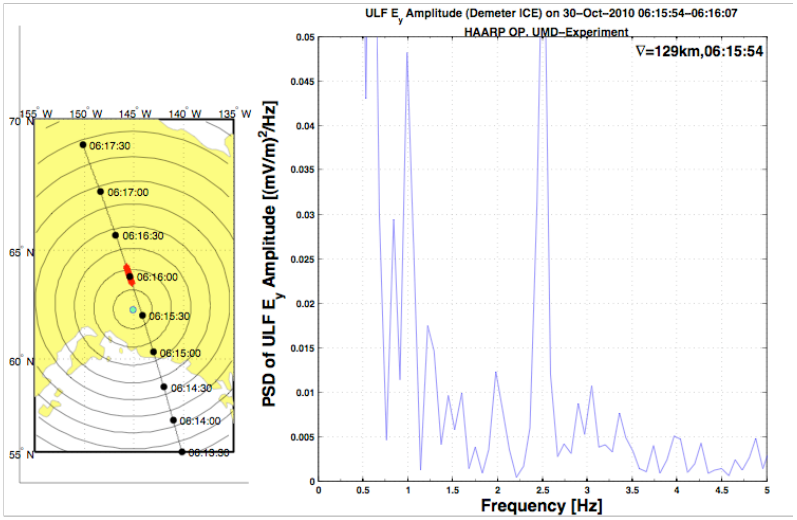
Demeter - Measurements

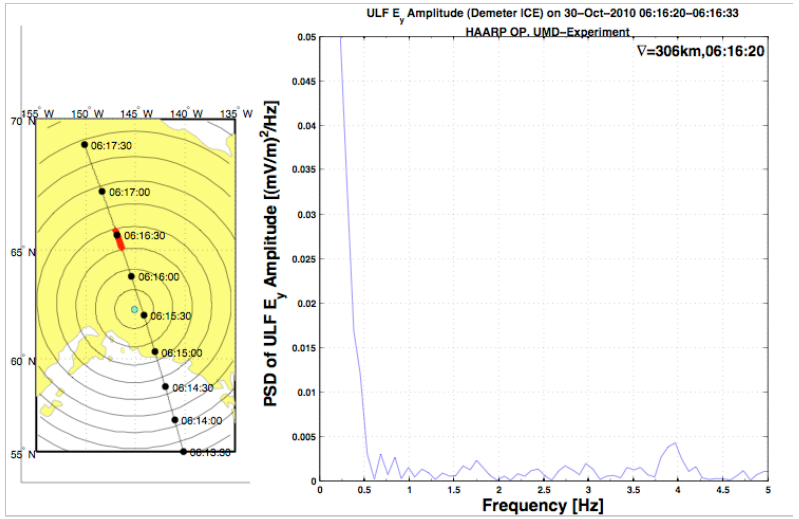
BRIOCHE

Chang-Milikh-Papadopoulos

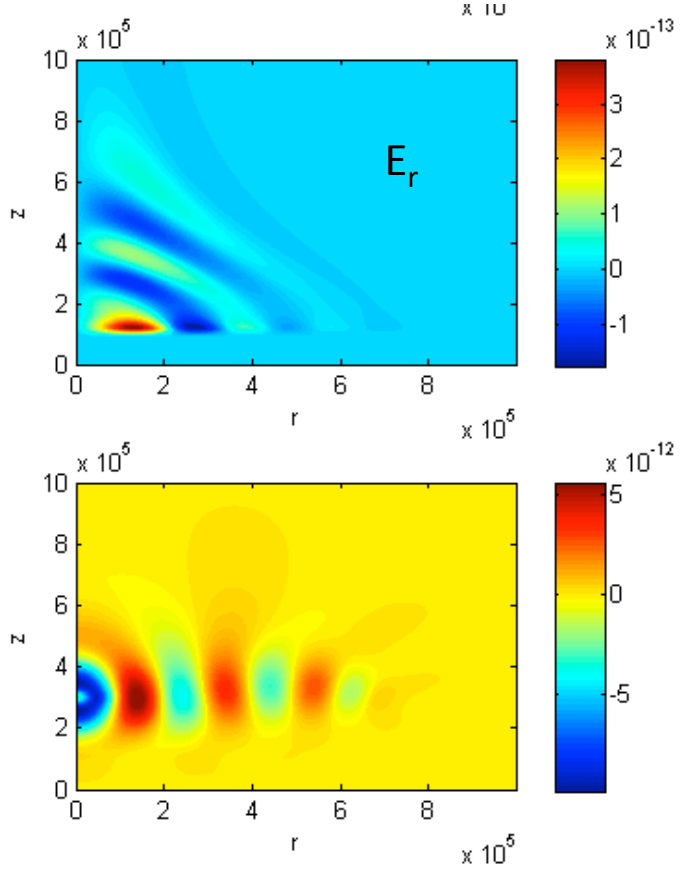


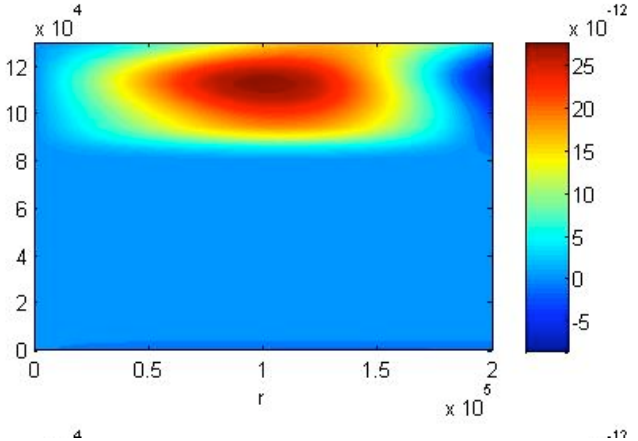




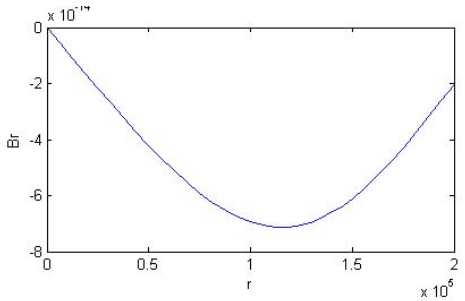


So what creates the field on the ground ?





E- region current J_θ



B_r field on the ground Near field

$$B_{gr} \propto J_\theta \propto \Sigma E \propto \Sigma(\lambda) P_{HF}$$

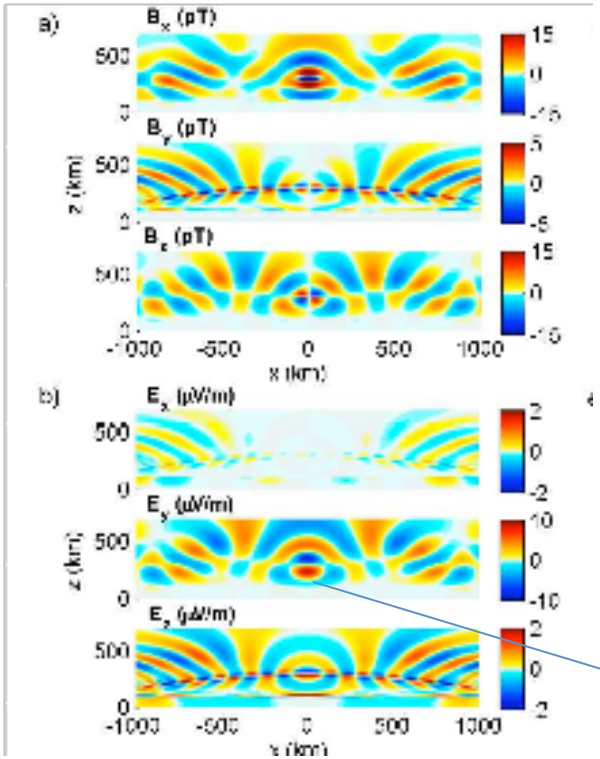
Consequences:

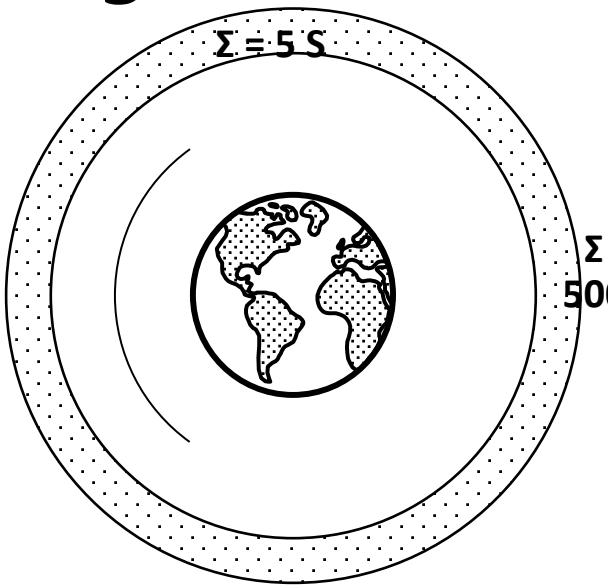
1. ICD can provide ELF at all times and at all latitudes

2. It can provide a ship-towed mobile ELF system

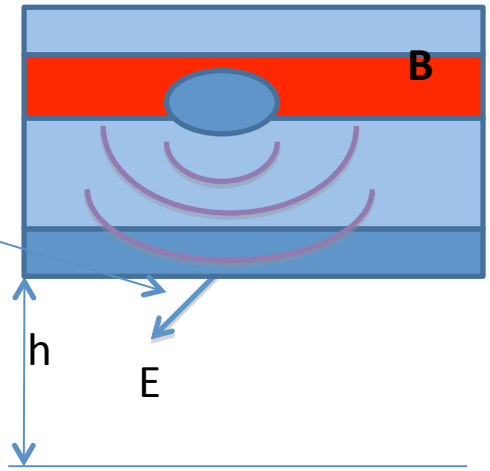
ICD Scaling with Geomagnetic Latitude

Dip Equator





Cowling effect

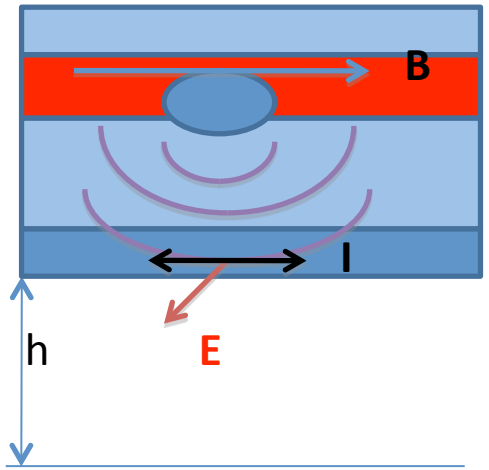


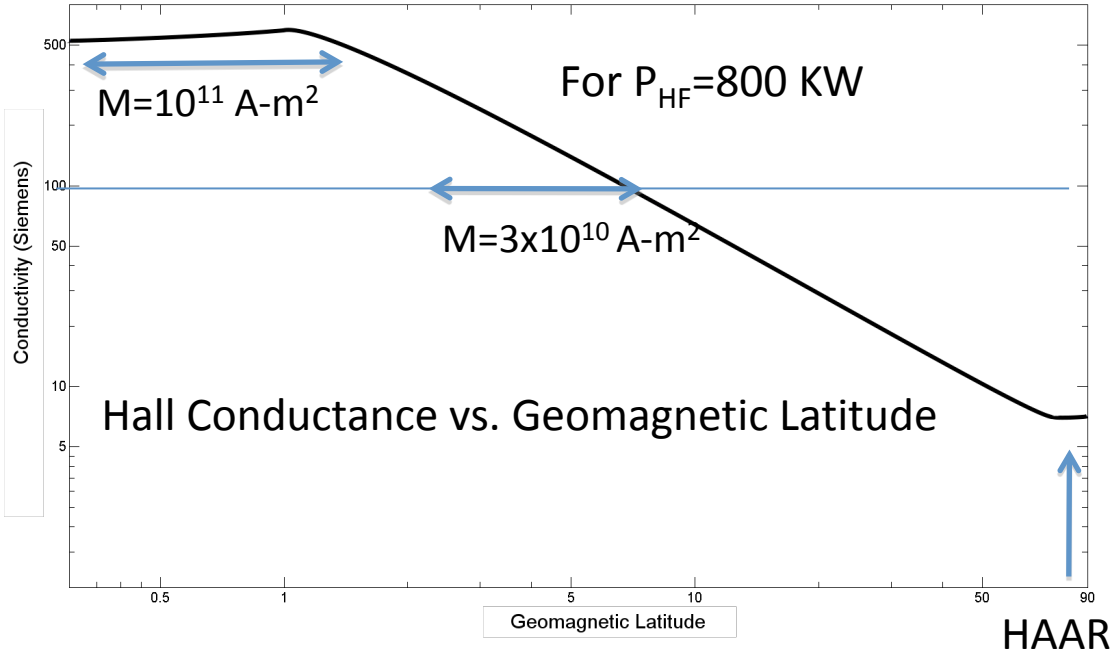
$M \approx \Sigma E L h \sim \Sigma, \quad \Sigma(\lambda=0)/\Sigma(\lambda=90) \approx 100$

$$M(\lambda, P_{HF}, f) = M_o[\Sigma(\lambda)/\Sigma_o][P_{HF}/3.6MW][12Hz/f]$$

$$M_o \approx 4 \times 10^9 A - m^2$$

ICD Scaling with Geomagnetic Latitude





HAARP

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

$$M_{eff}(\lambda) \approx (4\times10^{9})[\frac{\Sigma(\lambda)}{5S}](\frac{P_{HF}}{3.6MW})A-m^2 \approx$$

$$\approx (2.4\times10^{8})\Sigma(\lambda)(P_{HF}/MW)A-m^2$$

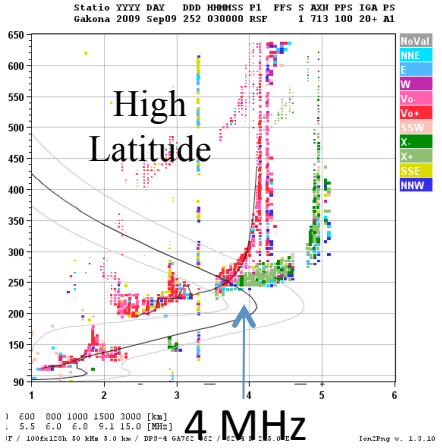
For P_{HF}=800 kW we get
M_{eff}≈10^{11} A-m^2 at λ≈0
M_{eff}≈3x10^{10} A-m^2 at λ≈6°

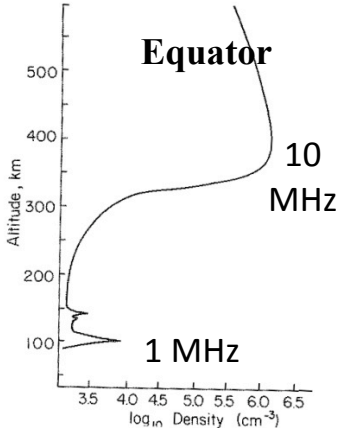
Parameters allow us to consider an equatorial barge basing of the HF transmitter

Barge or Shipboard Option

Strawman HF Array

- HF frequency 5-8 MHz
- Linear polarization
- Power on ship or self-propelled platform

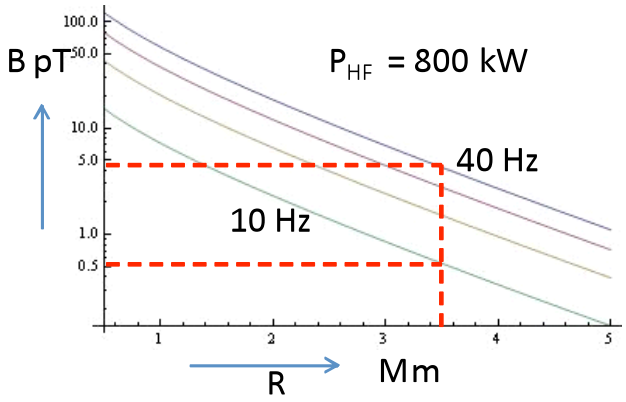


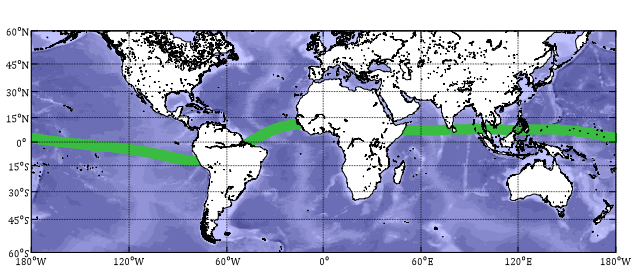


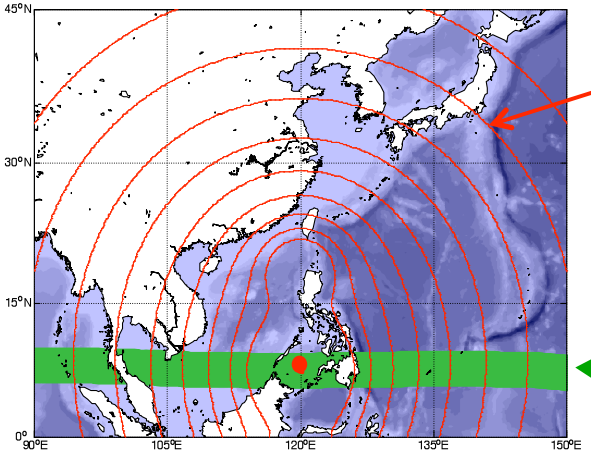
- Can provide strategic and tactical sub communications

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/$Hz^{1/2}$







800 kW HF System
5 pT line at 40 Hz

Optimal Region
For ELF Array

Equatorial Test System

- Simplified, lower-cost system based on proven HAARP design
- Relocatable and easily expandable -- can be expanded into operational TX when tests are complete
- Fully modular, designed for easy relocation
  - transmitters in transportable shelters
  - antennas and ground screen designed for simple relocation
  - minimal site preparation (concrete foundations for antennas)
- Use existing high power tubes as GFE (e.g. 100 kW OTH-B tubes)
  - minor antenna and feed modifications needed
- Antenna is scaled, simplified version of HAARP low band antenna
  - resized for 5-8 MHz (about half the size of current HAARP antennas)
  - simplified installation and guiding system with modular ground screen or no screen

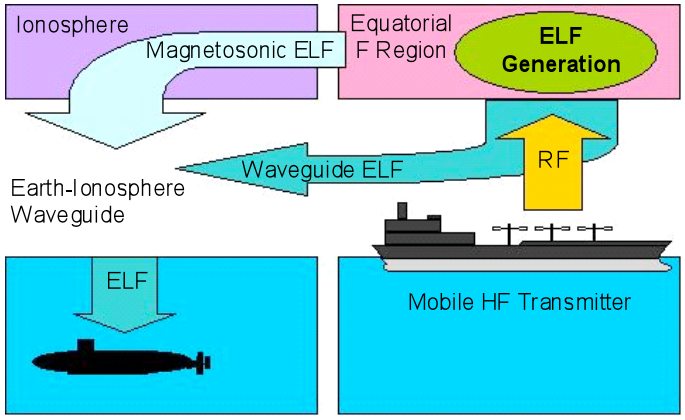
Next Step

8-10 month effort to

- Design an equatorial HF-ELF system
  - Requirements for sub-comm.
    - Power, frequency (match local ionosphere), ELF generation efficiency, coverage area, bit rate..
  - Trade space
    - Cost & performance: OTH-B surplus (tube) vs. solid state
  - Cost & risk analysis
    - Availability & usability of OTH-B equipments
  - Site survey & selection
    - Supporting infrastructures, local power grid, land use
- Develop program with options:
  - Cost, schedule, risks and mitigations
  - Go/NoGo criteria between program phases

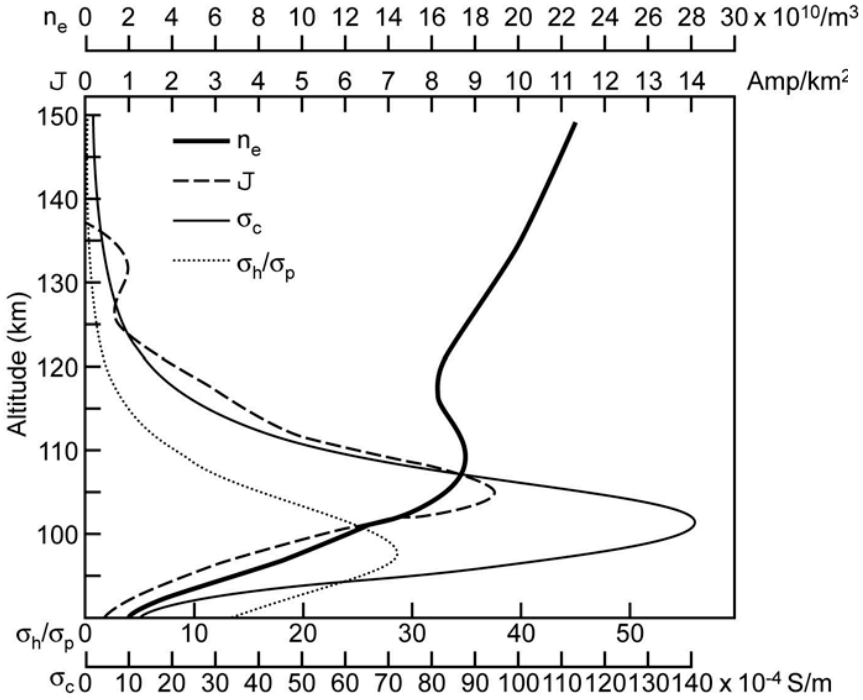
SUMMARY

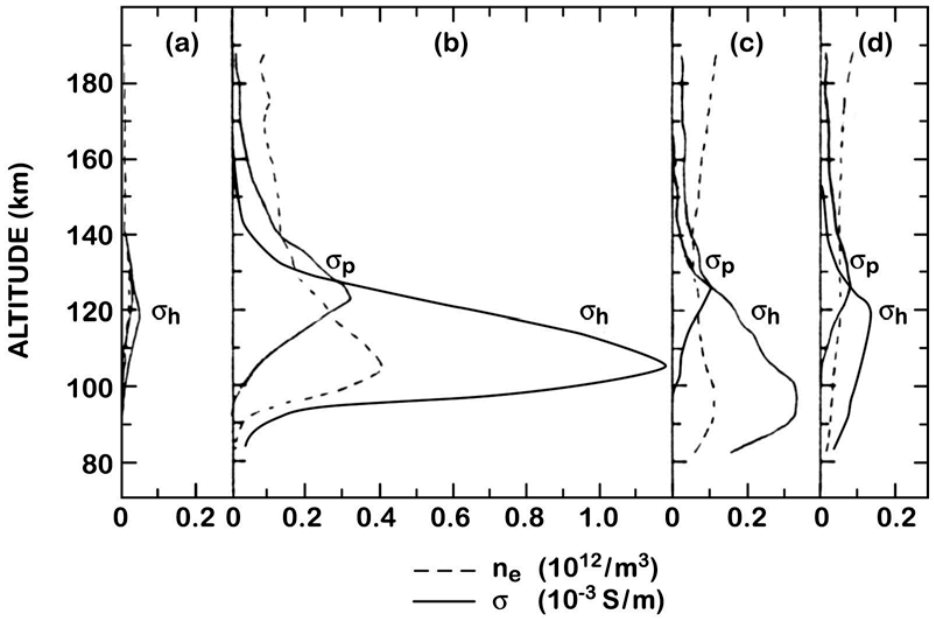
- ELF produced by HAARP with ***NO Electrojet*** – ***A Major Breakthrough*** based on discoveries in recent HAARP campaigns under MURI/ONR and BRIOCHE/DARPA programs
  - Predictable and repeatable ELF generation up to 50 Hz on daily basis
  - $M_{eff} \approx 4x10^9$ A-m^2
  - Validated technique: plasma currents driven by HF heating in the F/E layers
  - Technology transferable to low latitude regions with robust F & no E'Jet
- An efficient Ionospheric ELF source that can be positioned in theater on a mobile platform
  - Data rate >> FELF system
    - Higher source strength
  - High TRL level for transitioning



Supplementary Slides

Comparison of equatorial and auroral conductivities

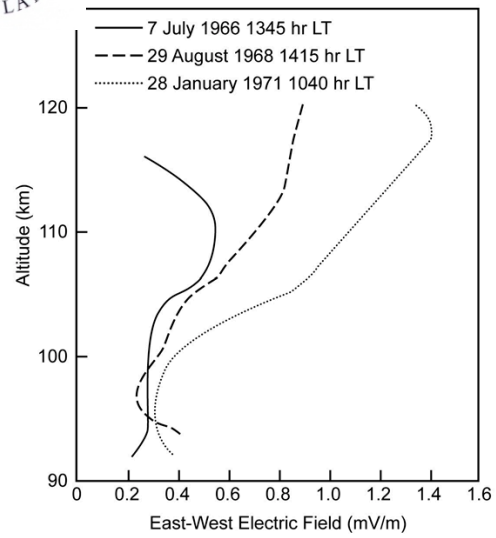




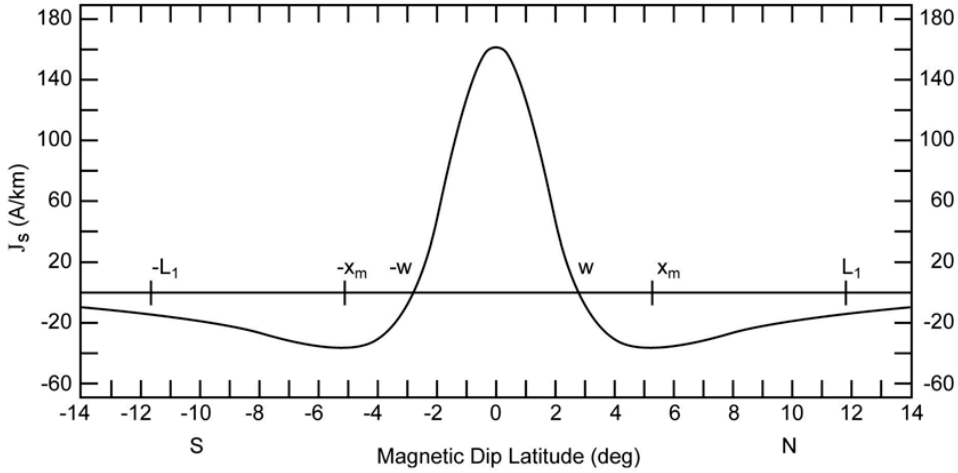
Equatorial
14×10^{-3} S/m

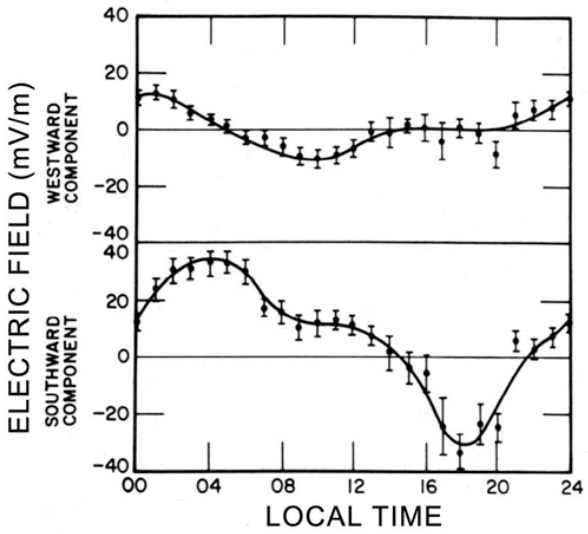
Auroral
1.2×10^{-3} S/m

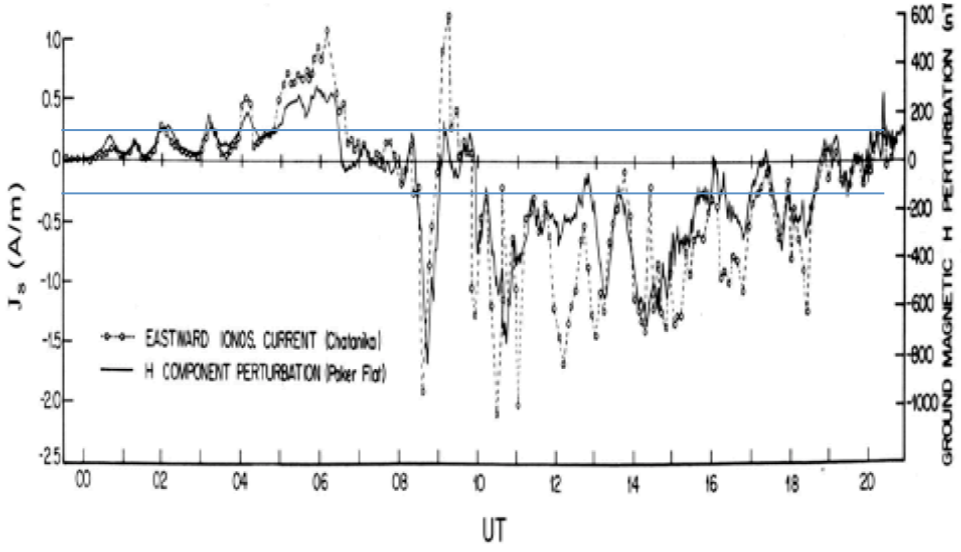
Comparison of Equatorial and Auroral Electric Fields and currents



Equatorial







Auroral

The Dip Equator