# HF Communication Disruptions from Disturbed Ionosphere Conditions

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Space Weather Effects on Aviation
Fall 2015 FPAW Session at NBAA Annual Convention
November 18, 2015

# HF Propagation

- HF technically covers 3-30 MHz
- International HF aeronautical bands are between 2.8-23.3 MHz so most of HF is available
- Long distance HF (~300-3000 km and beyond) relies on a “skywave” reflected from the ionosphere
- Knowing what the ionosphere is doing is crucial to knowing what HF will do

# Propagation

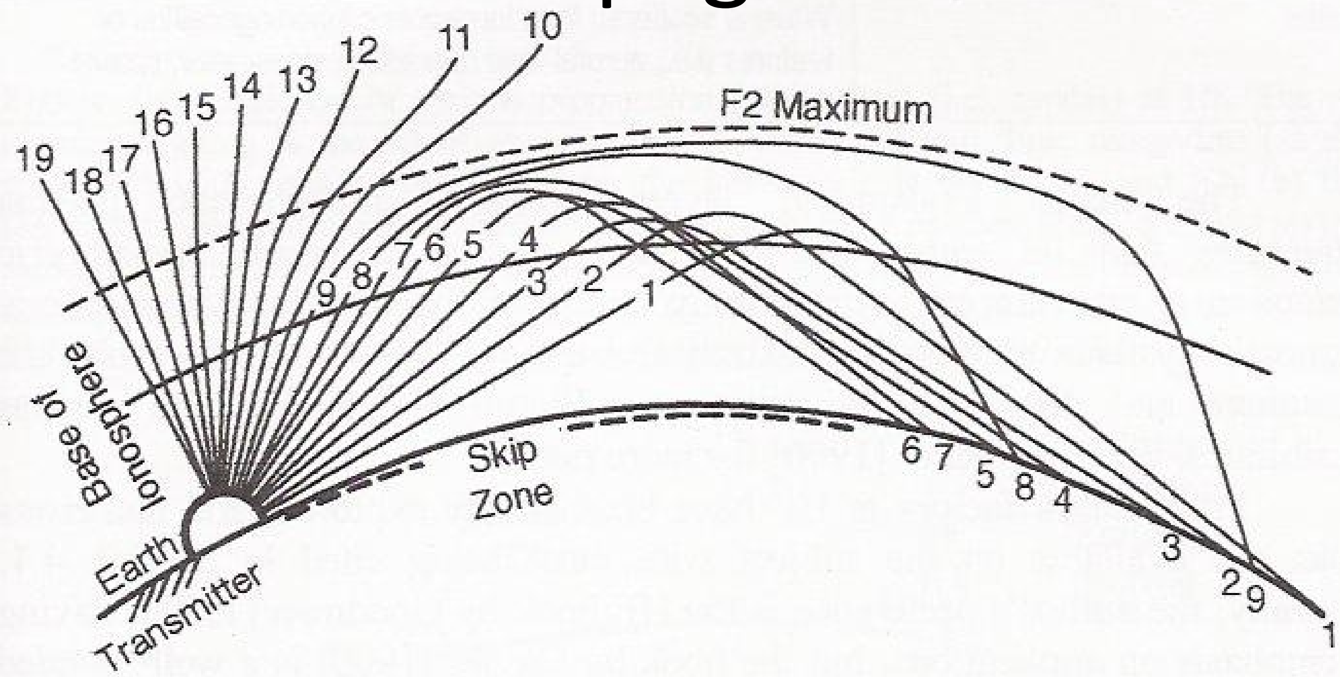



**Figure 4-5**: Illustration of rays launched into the ionosphere. The numbers are sequenced from the lowest elevation angle labeled "1" at 0 degrees to "19" at 90 degrees. Notice that rays 1-9 participate in skywave propagation, and rays 10-19 escape through the ionospheric iris. A "skip zone" is also introduced. In practice this skip distance is weakly illuminated as the result of non-classical scatter modes. Groundwave and line-of-sight propagation will also provide "local" coverage.

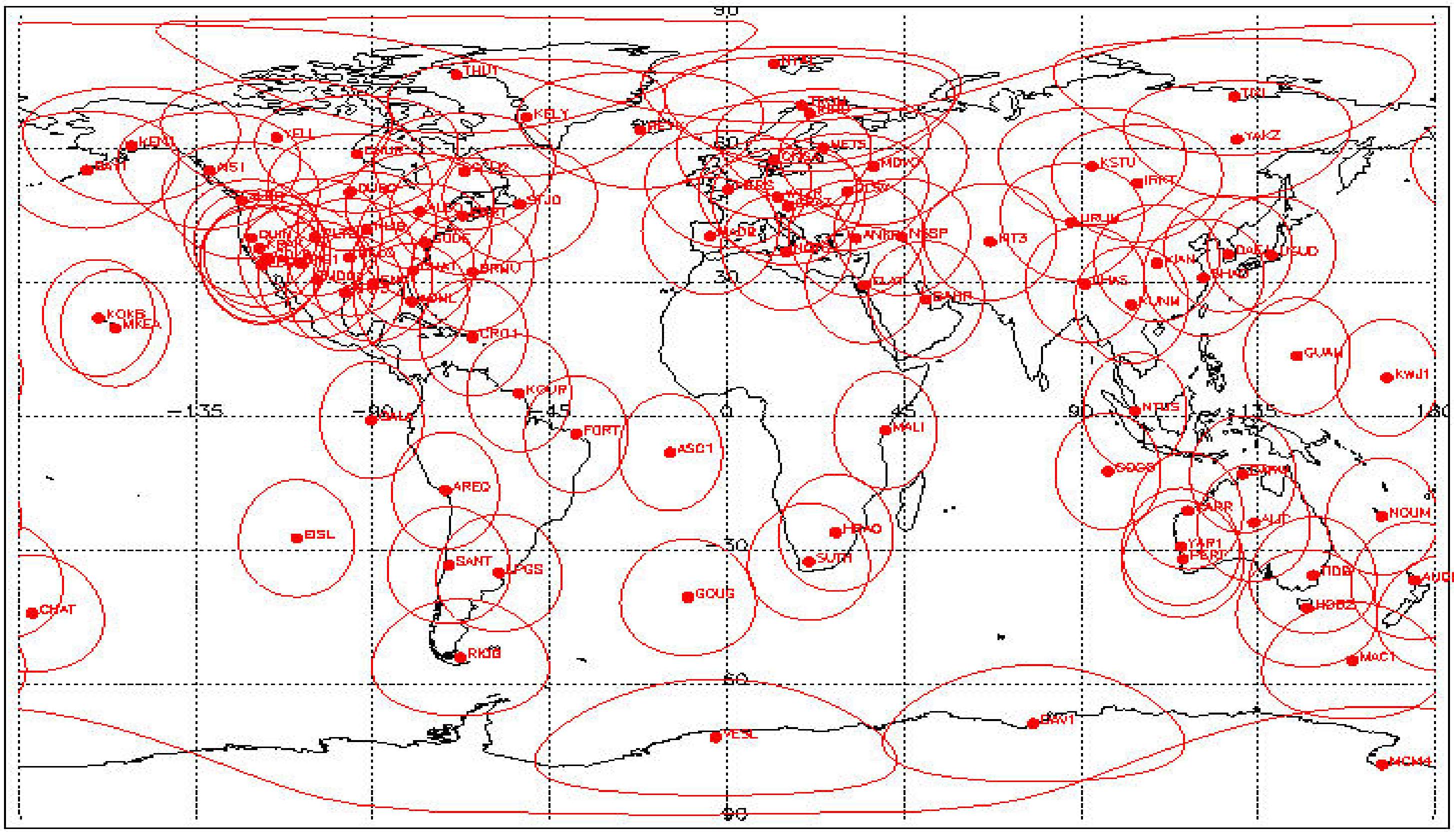
**Credit: Goodman**

# What is the Ionosphere Doing?

- The current state of the ionosphere can be observed with:
  - Ground-based instruments such as radars
  - Satellites
- Computer models are used to fill in the gaps between observations, and provide forecasts
- The USU GAIM model “assimilates” thousands of global observations to estimate and forecast ionospheric conditions

# TEC Coverage of <u>Daily</u> IGS Ground Network

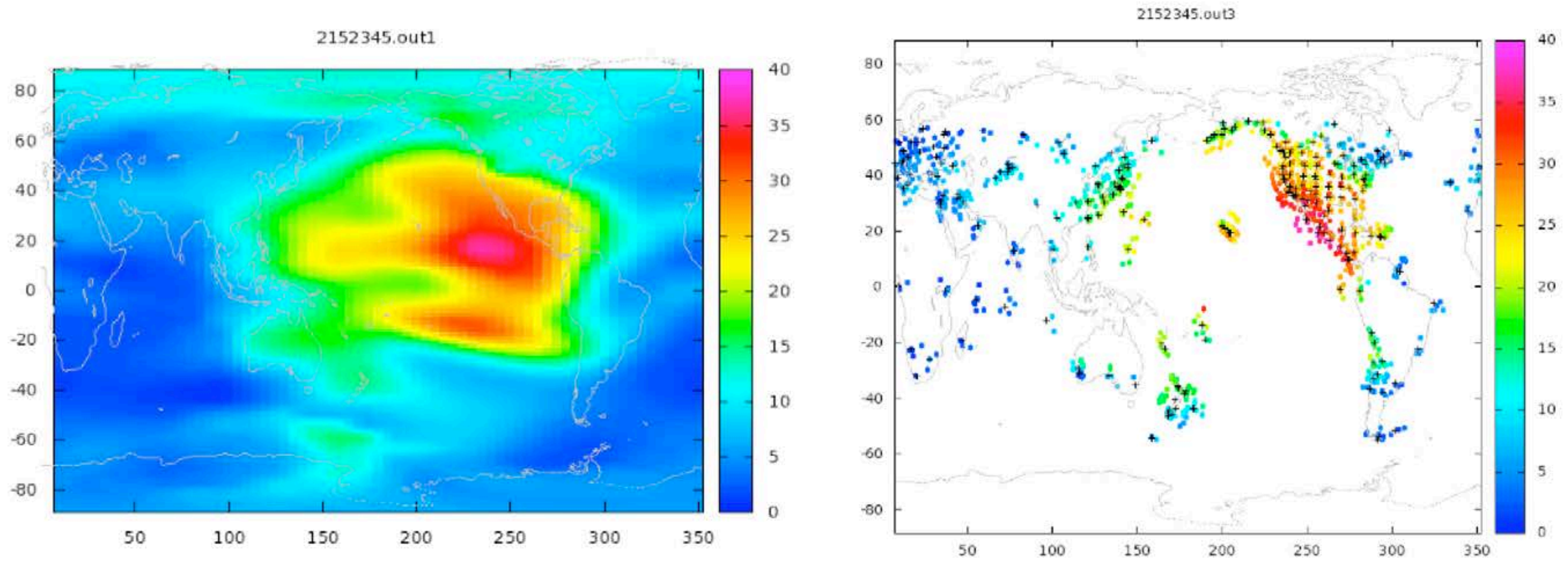
**(10 degree elevation mask; 450 km shell height)**



**Credit: USC/JPL**

# GAIM-GM Global Run

- 357 global TEC stations (IGS network) used in real-time at USU Space Weather Center
- Up to 10,000 measurements assimilated every 15- min
- 40-50 Ionosondes/Digisondes

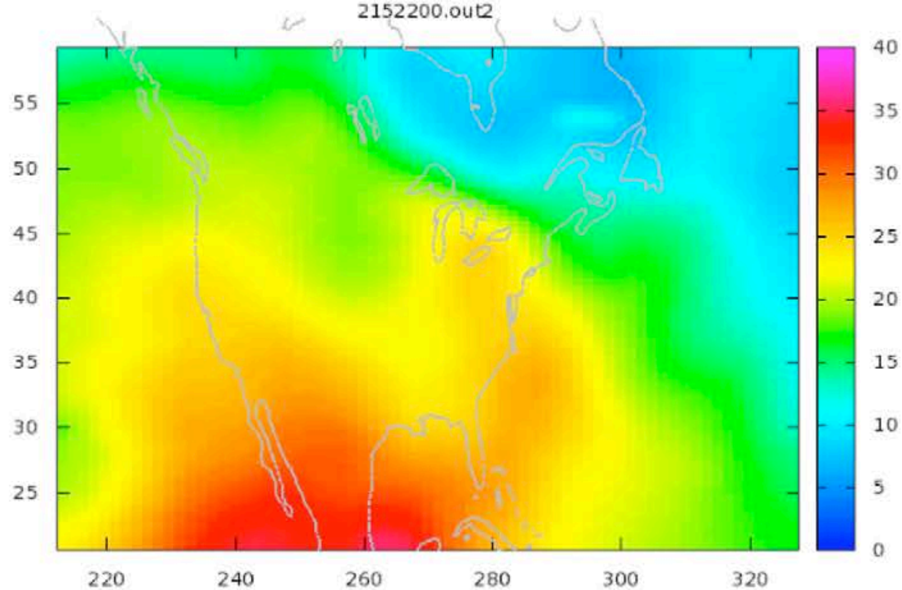


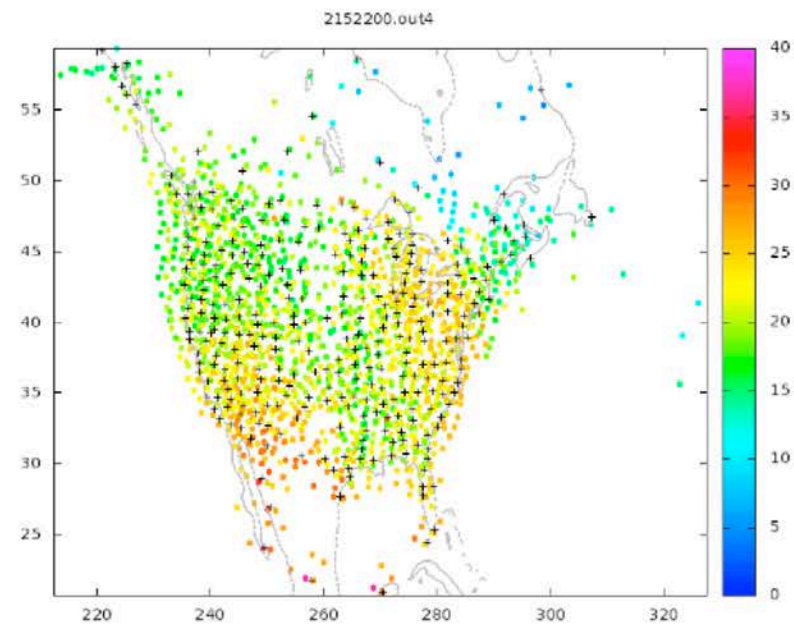

"Bringing The Pieces Together"

UtahStateUniversity

# GAIM-GM Regional (High Resolution) Run:

- 424 USTEC stations (CORS network) used in real-time at USU Space Weather Center
- Up to 10,000 measurements assimilated every 15-min

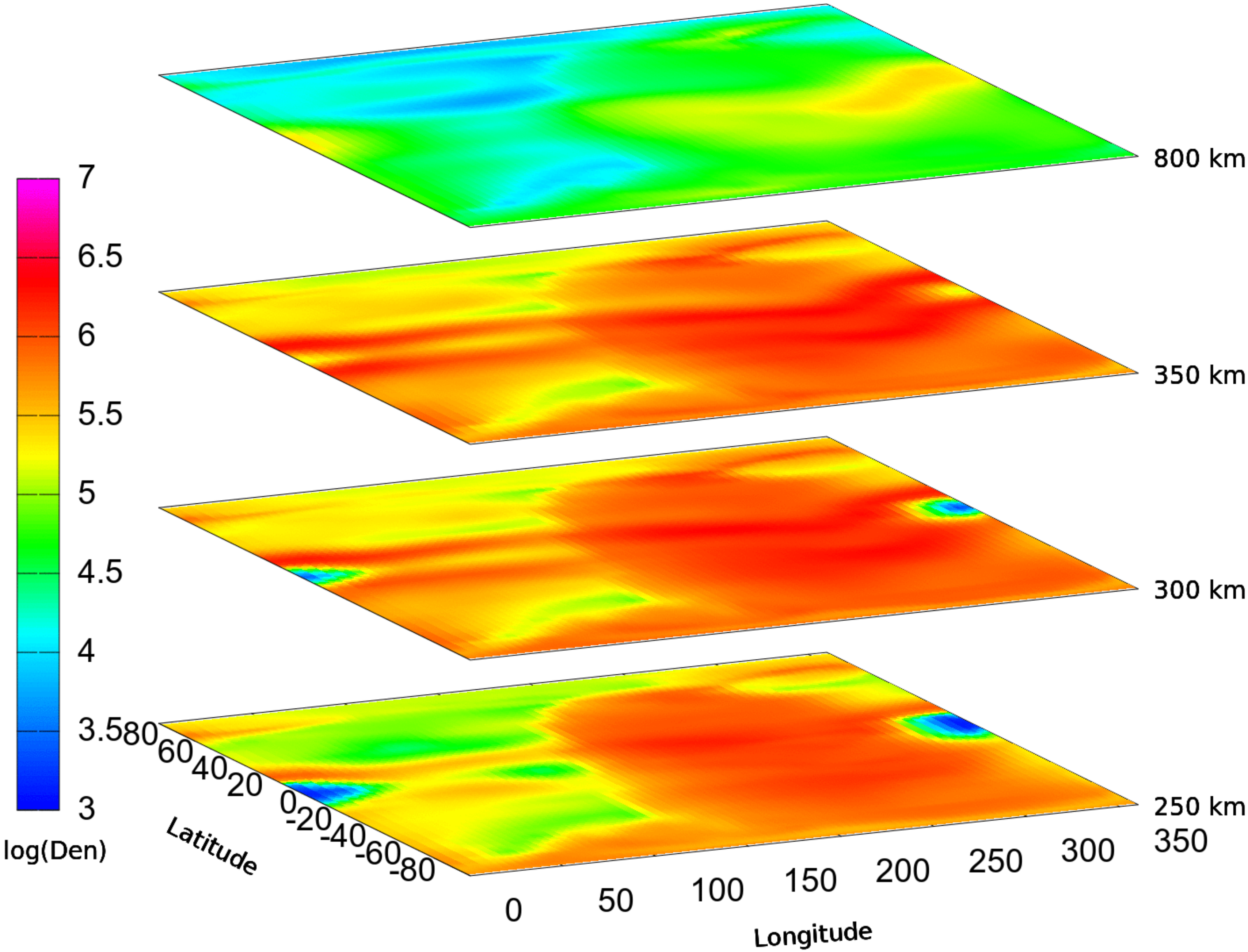



G A I M

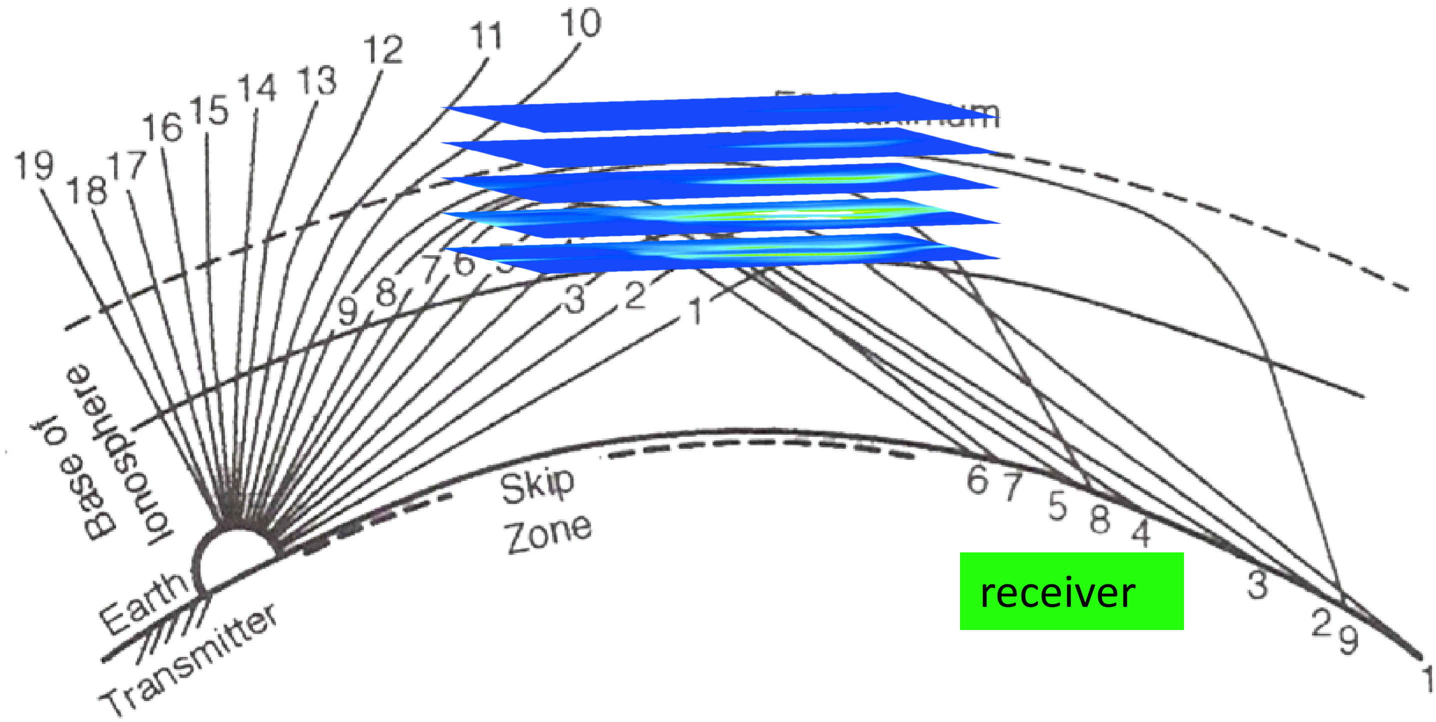
UtahStateUniversity

GAIM simulates slices of the ionosphere (in finer resolution than shown here)




11/6/2015 DOY:310 20:00 UT

HF signals reflect off the ionosphere to other Earth locations and these paths can be ray-traced for given transmit/receive locations.



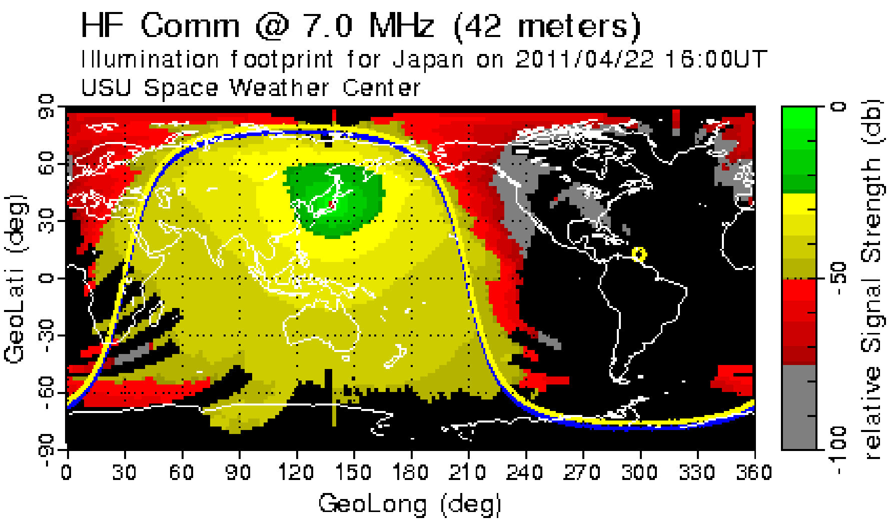
# USU Space Weather Center
# High Frequency (HF) Communications Product

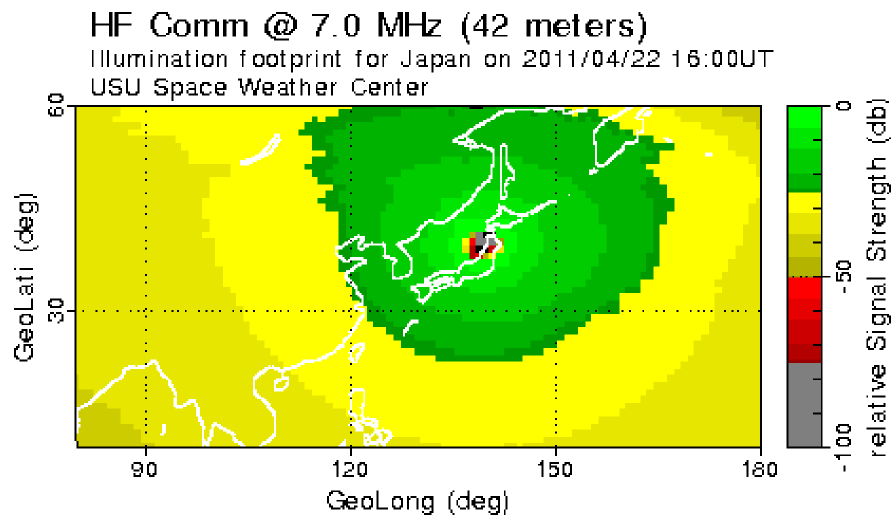
- USU SWC combines models and utilities to provide HF propagation information
- 3-hour forecast of frequencies
- Recommendation of available frequencies to global operators
- Available HF frequencies for Emergency Responders
- Applications for aeronautical HF users have been explored

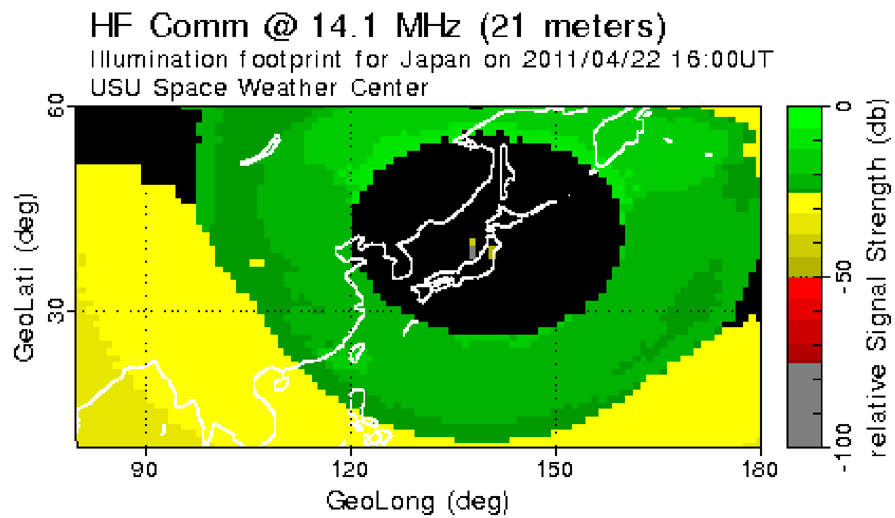

# USU SWC HF Support for Emergency Responders using Amateur Radio

# HF GCSS -- HF Signal Strength Footprint from a single transmitter-receiver

## (Who can I hear and who can hear me?)




MAP calculated to indicate where signals can propagate from and to a TX-RX

- Green – good signal
- Yellow – adequate signal
- Red – inadequate signal
- Gray – extremely weak signal
- Black – No Signal

# Aviation Air-to-Ground HF Tool

- Developed tool to help pilots find the best current HF communications links.
  - Green: good signal
  - Yellow: adequate signal
  - Red: inadequate signal
  - Gray: signal strength gone
  - Black: No propagation

**Air Traffic Control Station with Best Signal**

| Location | UTC | ATC | Distance (km) | Frequency (kHz) | dB* |
|---|---|---|---|---|---|
| **35N150E : (LAT:35 LON:150)** | | | | | |
| | 2011-05-02 02:00:00 | NYC | 13310 | 10375 | -151 |
| | 2011-05-02 02:00:00 | NYC | 6625 | 10375 | -283 |
| **35N160E : (LAT:35 LON:160)** | | | | | |
| | 2011-05-02 02:00:00 | ORD | 17946 | 8935 | -133 |
| | 2011-05-02 02:00:00 | ORD | 13310 | 8935 | -147 |
| **33N180E : (LAT:33 LON:180)** | | | | | |
| | 2011-05-02 02:00:00 | SLC | 17946 | 5900 | -124 |
| | 2011-05-02 02:00:00 | NYC | 17946 | 8765 | -127 |
| **28N170W : (LAT:28 LON:190)** | | | | | |
| | 2011-05-02 02:00:00 | ANC | 17946 | 3910 | -119 |
| | 2011-05-02 02:00:00 | SFO | 17946 | 4470 | -119 |

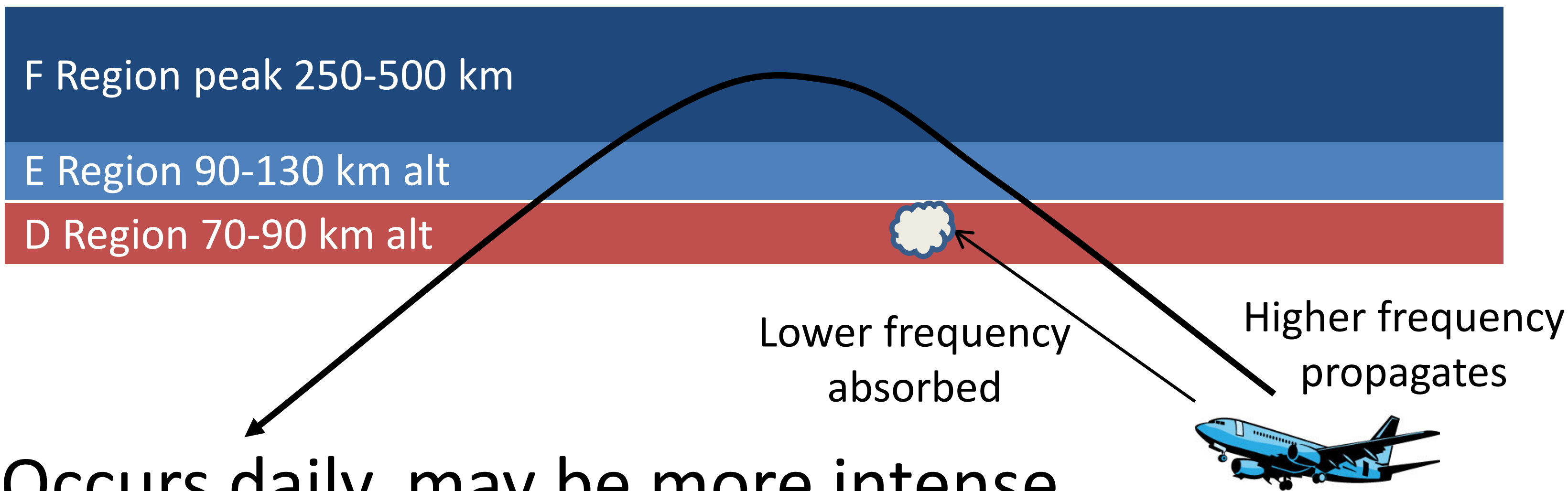
* dB Transmission Color Key: Green=Good : Yellow=degraded: Red=Poor : Gray=unusable

# Space Weather and HF

- We have observation-based models of the ionosphere
- We have tools to find HF paths through the model ionosphere
- What happens when space weather makes things more interesting?

# Common HF Disturbances: Absorption

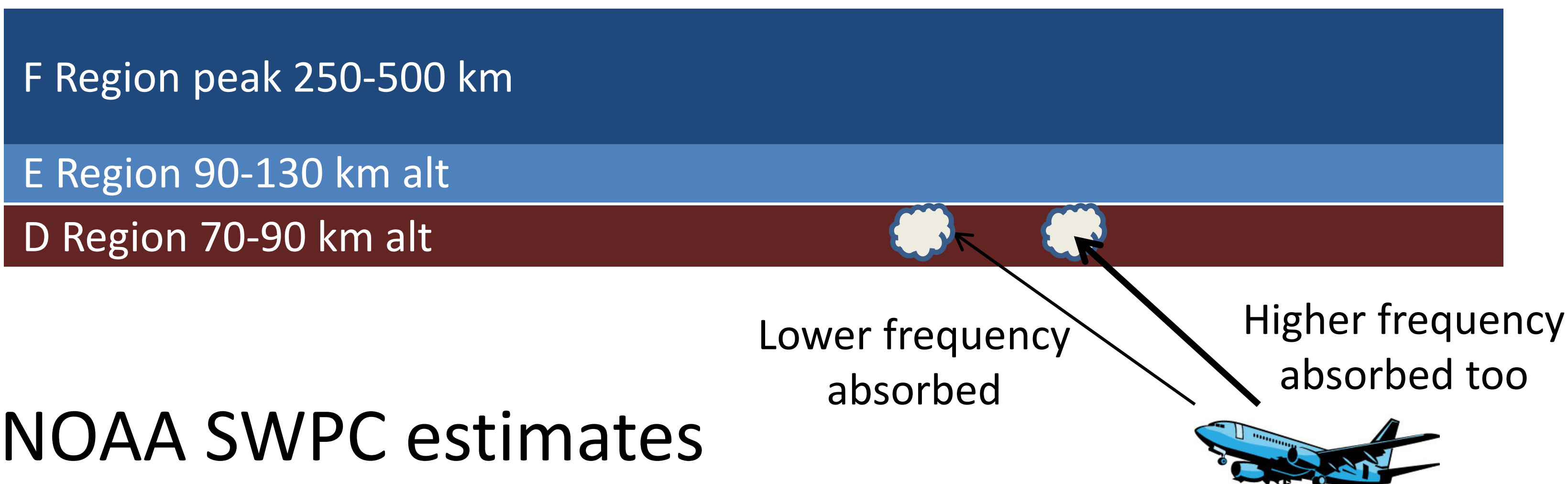
- **During the day**, sky waves (ionospheric reflections) below 3-4 MHz may be absorbed by the D region




- Occurs daily, may be more intense at times in winter (4-5 MHz)

# Common HF Disturbances: Flares

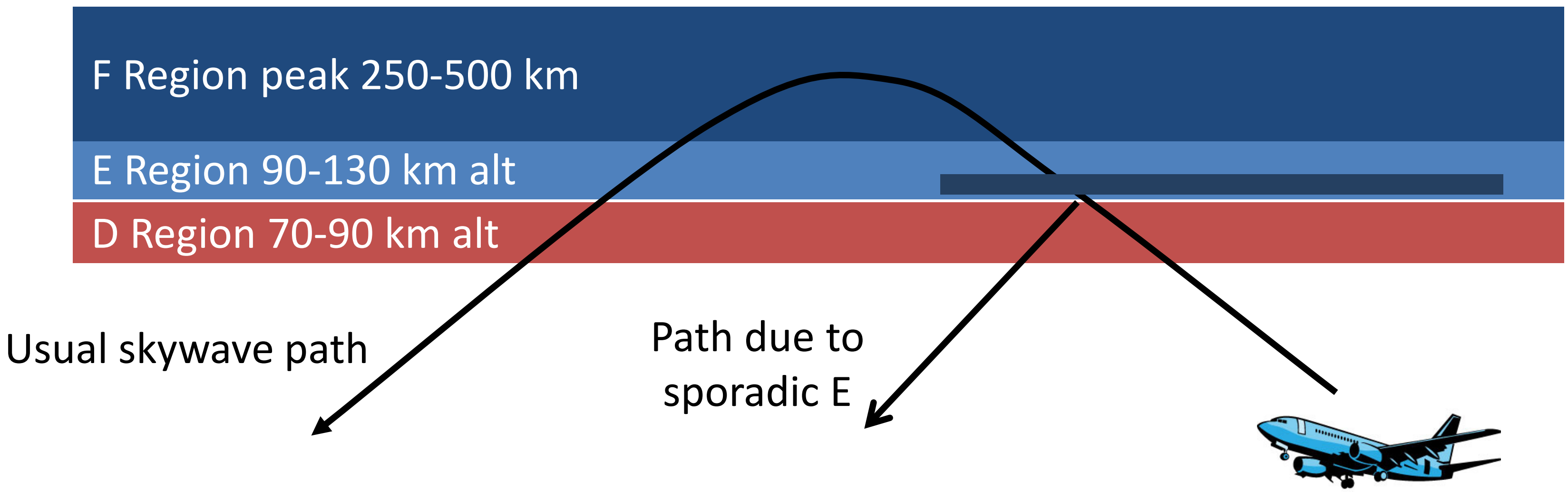
- **During the day**, solar x-ray flares may cause HF blackouts across most frequencies for 15 minutes to an hour.




- NOAA SWPC estimates the chance of flare occurrence

# Common HF Disturbances: Sporadic E

- An intense layer may appear around 100-120 km, drastically changing skywave paths
- Responsible for much HF and VHF "magic"



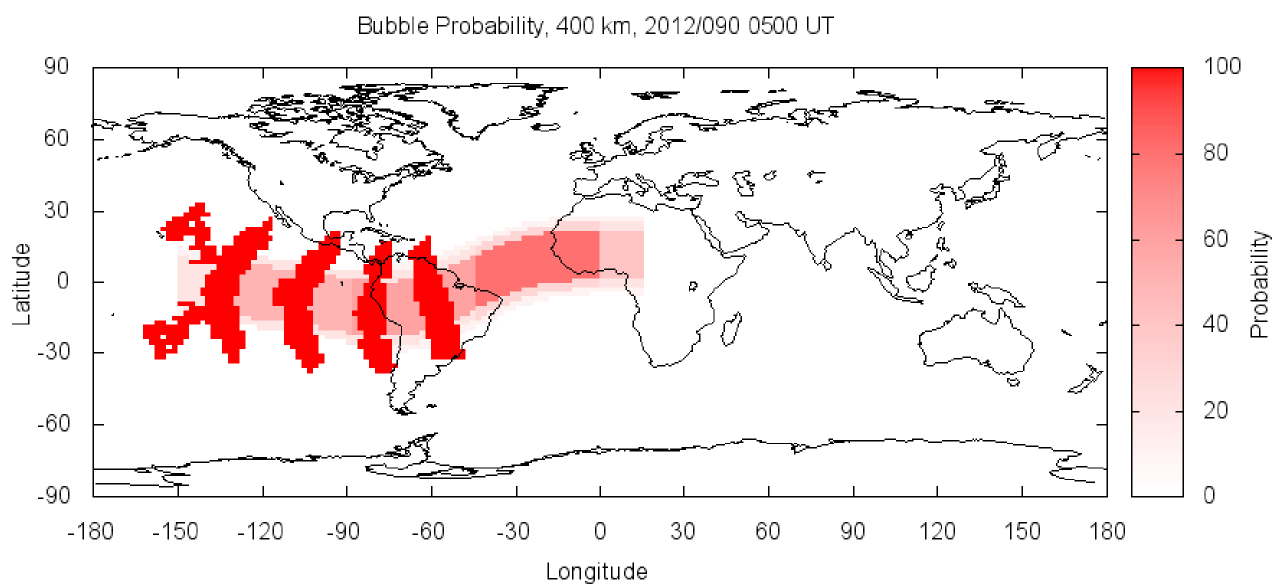

- May occur any time, but mostly midsummer and sometimes midwinter

# Other Common HF Disturbances

- Geomagnetic storms can cause unusual propagation
  - Normally reliable frequencies can become unusable
  - Signal quality may degrade: flutter and fading
- Ionospheric events can produce traveling ionospheric disturbances (TIDs) that produce HF fading and multipath

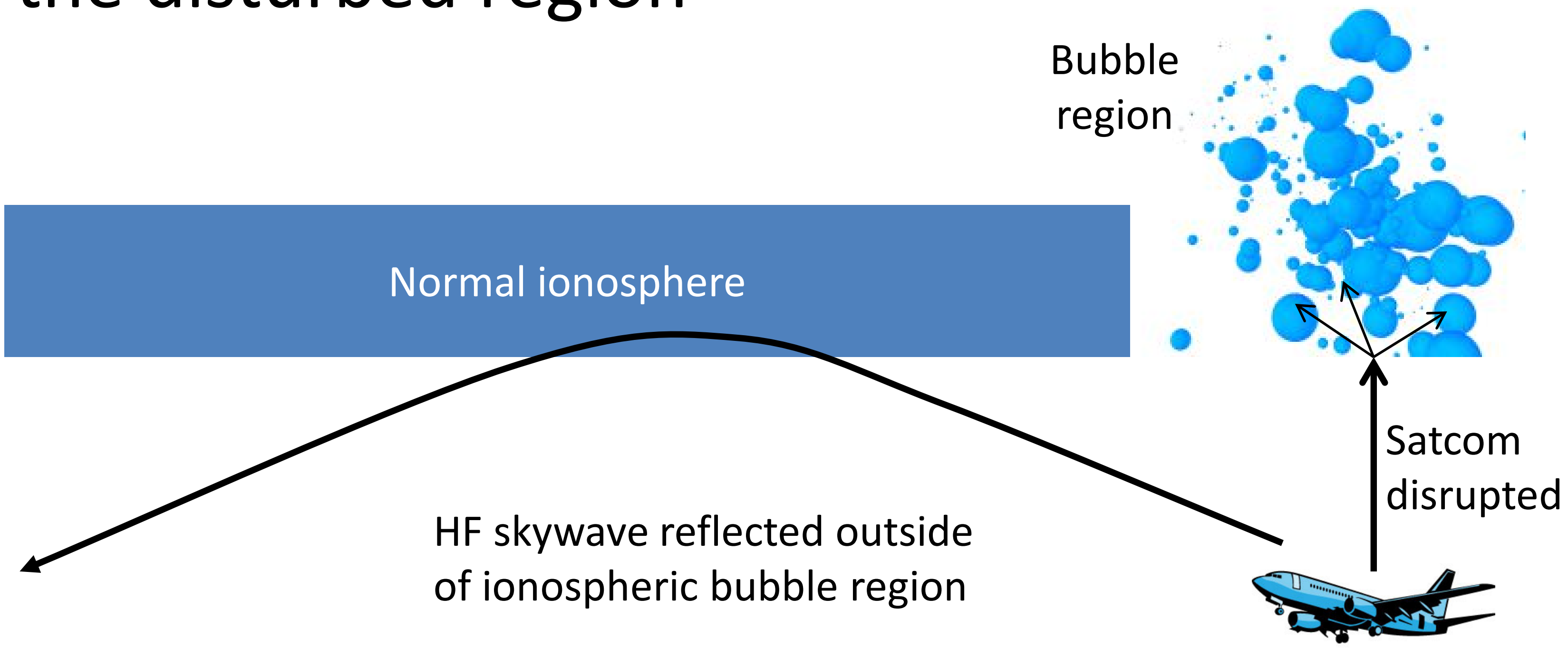
# Equatorial Disturbances

- Bubbles in the ionosphere along the magnetic equator can disrupt satcom and can distort HF



# Equatorial Disturbances

- Long-distance HF skywave paths may avoid the disturbed region



# Polar Disturbances

- HF propagation at high latitudes can be extremely complex
- HF models often do a poor job due to auroral and geomagnetic effects
- John Goodman found that the maximum usable frequency (MUF) was often 5-10 MHz higher than predicted by common models like VOACAP and ICEPAC

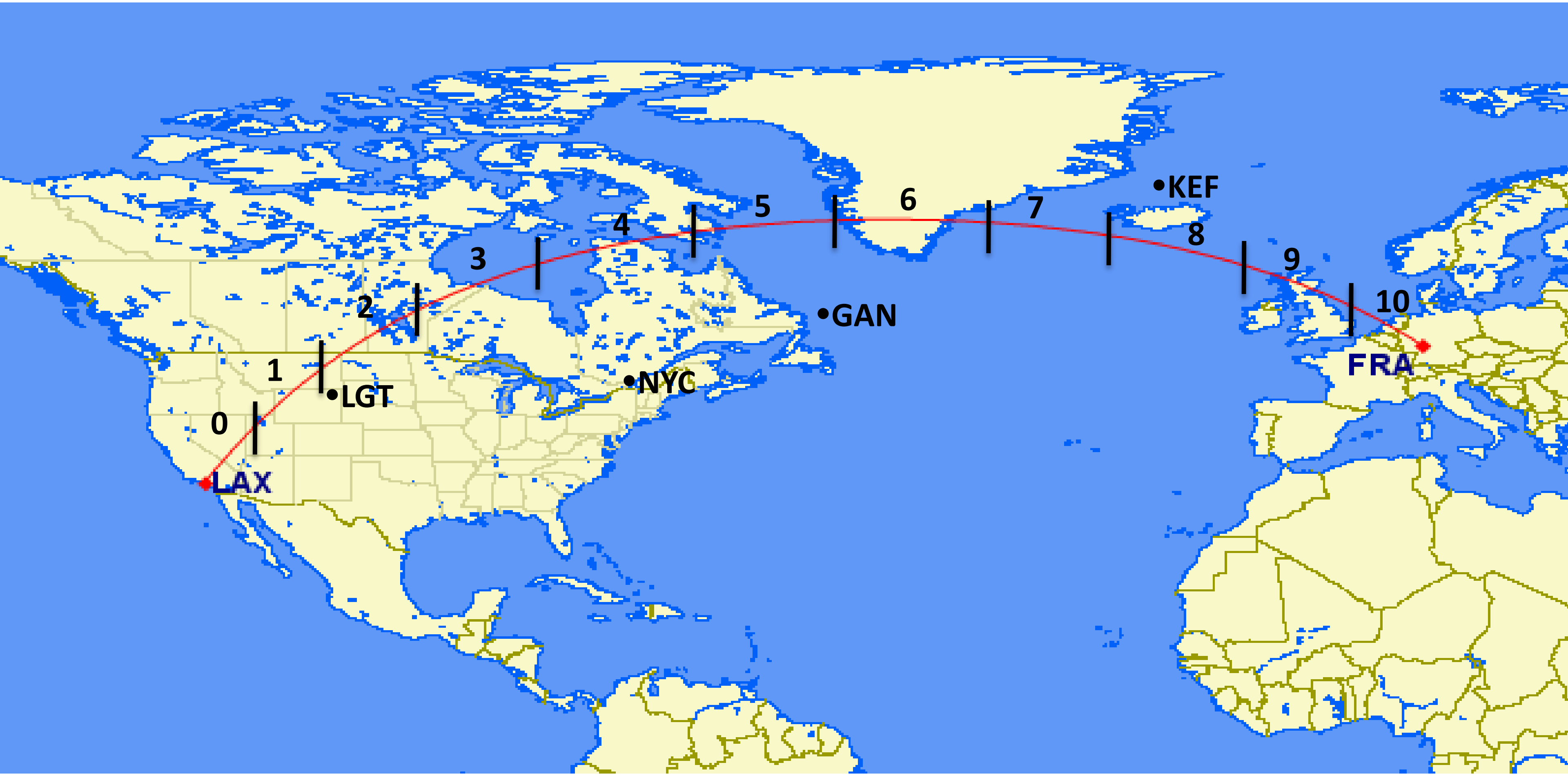
# Polar Disturbances

- At high latitudes, the ionosphere may develop blobs, patches, or holes that may enhance or disrupt normal HF paths
- Auroral sporadic E may be more common and stronger than the midlatitude sporadic E
- Magnetic field aligned structures can act as reflectors, sending HF waves off in unexpected directions
- Some of these conditions can interfere with satcom as well

# Polar Cap Absorption

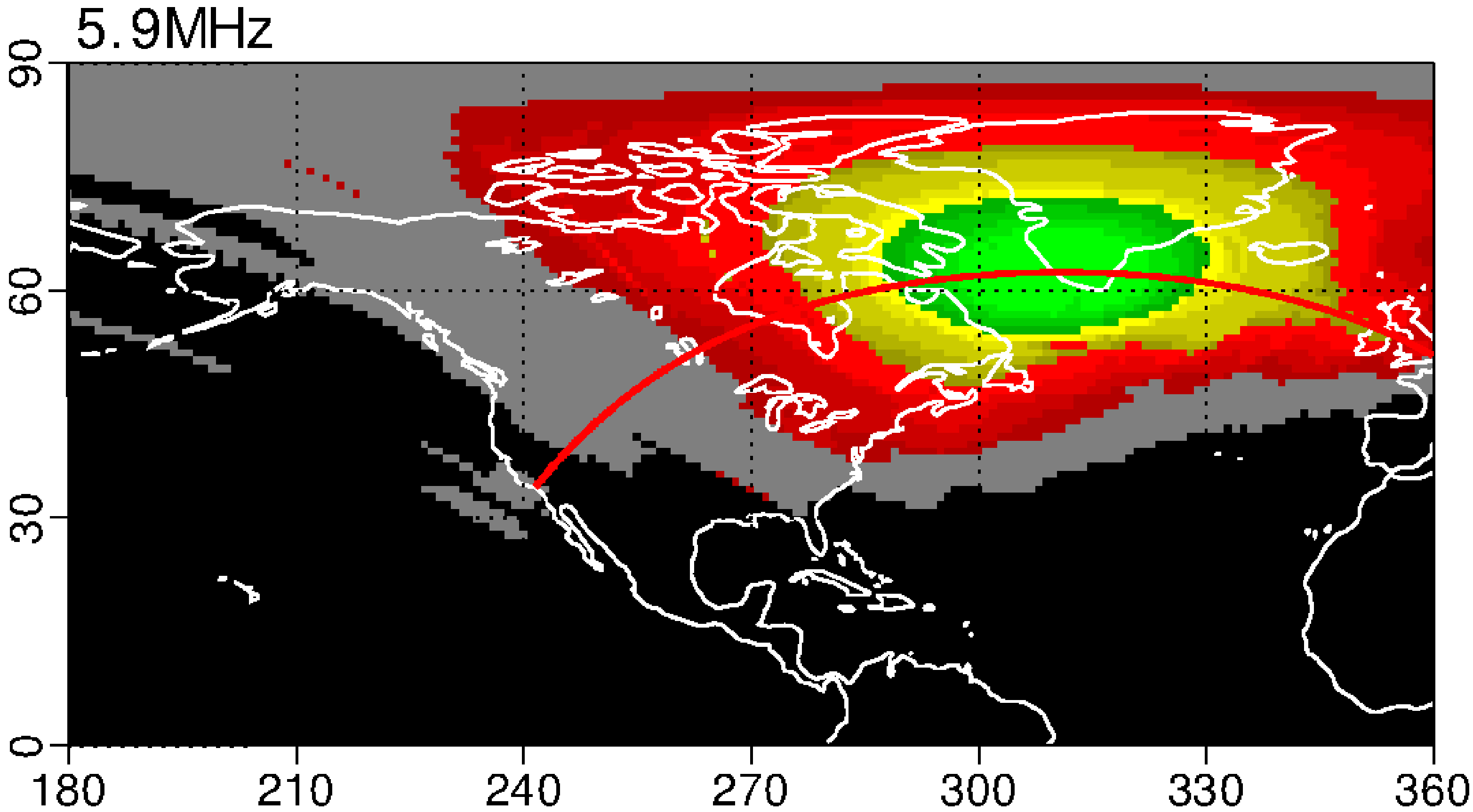
- Absorption at high latitudes is often more extreme than at midlatitudes, with short flare-like events affecting all HF frequencies
- A Polar Cap Absorption event (PCA) is even more extreme and can cause an HF blackout lasting for days
- May occur a few hours after a large solar flare
- Goodman’s observations suggest that the highest HF aeronautical frequencies might work in some cases during a PCA (auroral E?)

# Aeronautical HF PCA Impact



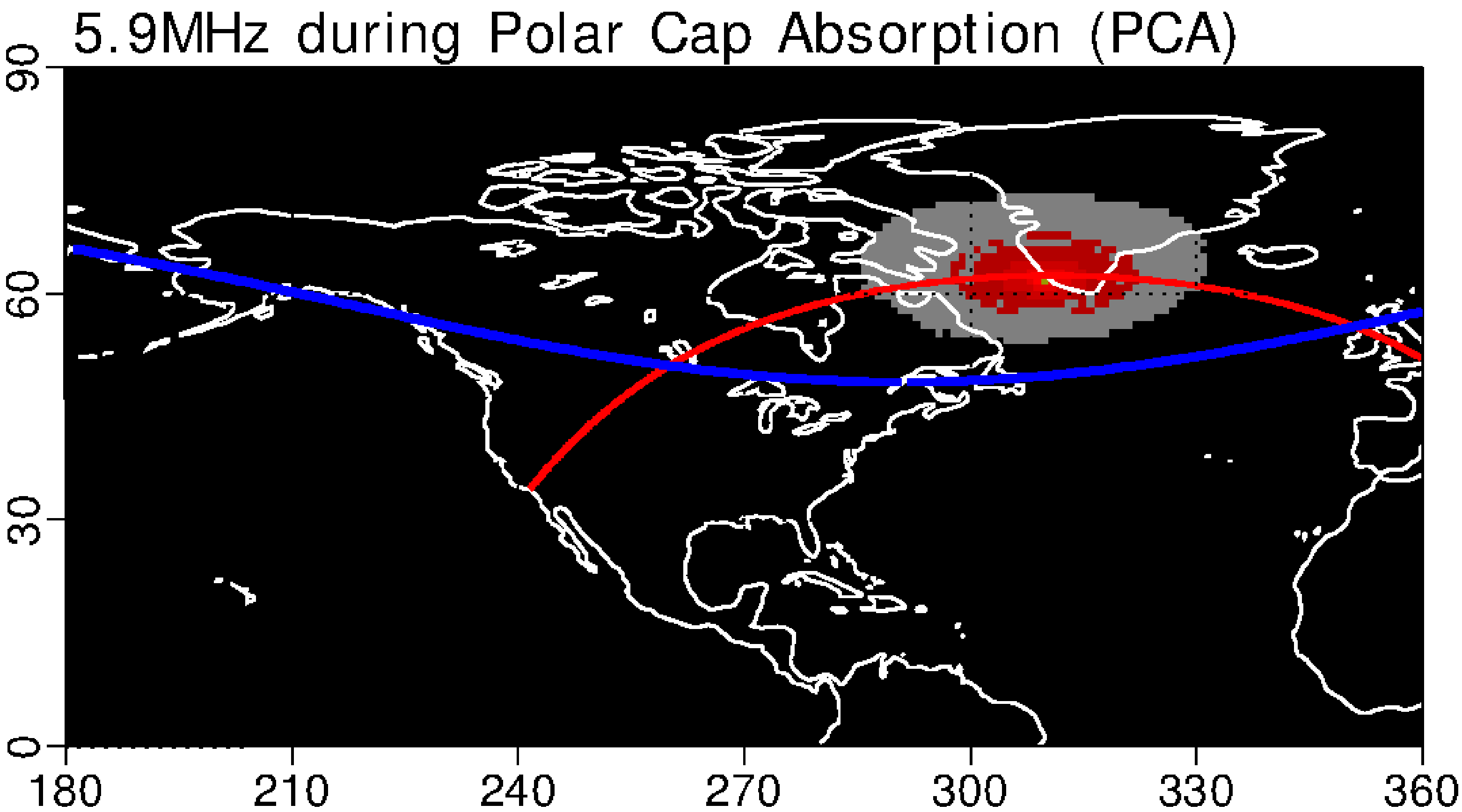

USU analysis of polar flight HF outage during a Polar Cap Absorption Event

# Aeronautical HF PCA: Before




Normal 5.9MHz HF propagation for flight approaching Greenland

# Aeronautical HF PCA: During



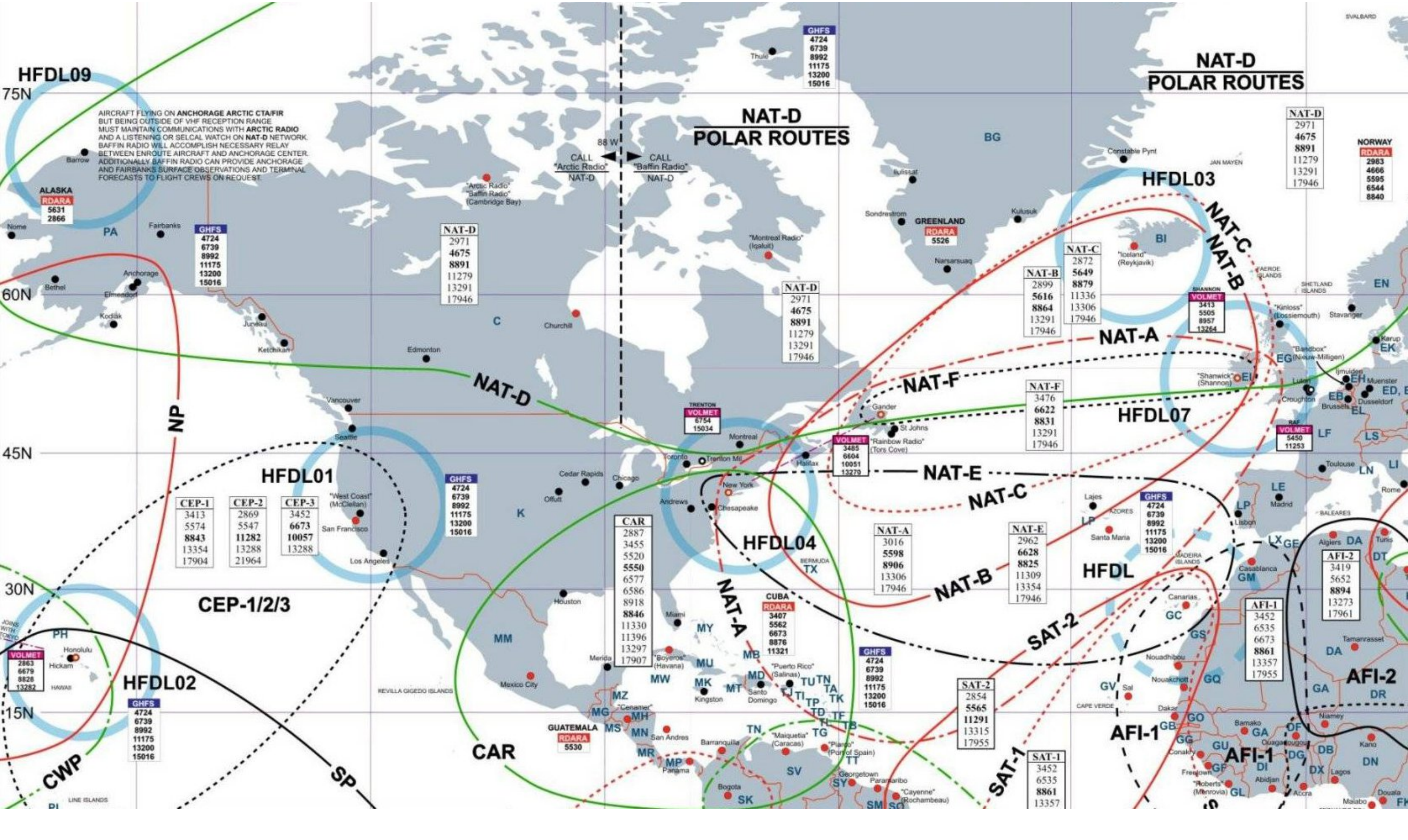

Polar Cap Absorption kills 5.9MHz HF propagation during Solar Storm

Solar Energetic Particles impinge on the N & S Polar caps to cause HF absorption

# Conclusions

- A variety of space weather events strongly affect HF communications, particularly in equatorial and polar regions
- The USU GAIM model can help forecast and work around some of these events
- More instrumentation in equatorial and polar regions is needed to improve results
- Such tools can help, but do not replace, HF operator skill and experience for successful HF communications

# Questions?



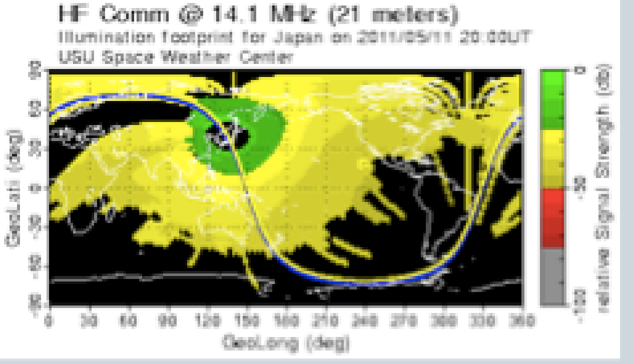
HFDL09
75N
60N
45N
30N
15N
AIRCRAFT FLYING ON ANCHORAGE ARCTIC CTA/FIR BUT BEING OUTSIDE OF VHF RECEPTION RANGE MUST MAINTAIN COMMUNICATIONS WITH ARCTIC RADIO AND A LISTENING OR SELCAL WATCH ON NAT-D NETWORK. BAFFIN RADIO WILL ACCOMPLISH NECESSARY RELAY BETWEEN ENROUTE AIRCRAFT AND ANCHORAGE CENTER. ADDITIONALLY BAFFIN RADIO CAN PROVIDE ANCHORAGE AND FAIRBANKS SURFACE OBSERVATIONS AND TERMINAL FORECASTS TO FLIGHT CREWS ON REQUEST.
88 W
CALL "Arctic Radio" NAT-D
CALL "Baffin Radio" NAT-D
NAT-D POLAR ROUTES
GHFS 4724 6739 8992 11175 13200 15016
ALASKA RDARA 5631 2866
NAT-D 2971 4675 8891 11279 13291 17946
NAT-C 2872 5649 8879 11336 13306 17946
NAT-B 2899 5616 8864 13291 17946
NAT-F 3476 6622 8831 13291 17946
NAT-A 3016 5598 8906 13306 17946
NAT-E 2962 6628 8825 11309 13354 17946
CEP-1 3413 5574 8843 13354 17904
CEP-2 2869 5547 11282 13288 21964
CEP-3 3452 6673 10057 13288
CAR 2887 3455 5520 5550 6577 6586 8918 8846 11330 11396 13297 17907
SAT-2 2854 5565 11291 13315 17955
SAT-1 3452 6535 8861 13357
AFI-1 3452 6535 6673 8861 13357 17955
AFI-2 3419 5652 8894 13273 17961
NORWAY RDARA 2983 4666 5595 6544 8840
GREENLAND RDARA 5526
CUBA RDARA 3407 5562 6673 8876 11321
GUATEMALA RDARA 5530
TRENTON VOLMET 6754 15034
SHANNON VOLMET 3413 5505 8957 13264
RAF VOLMET 5450 11253
VOLMET 3485 6604 10051 13270
VOLMET 2863 6679 8828 13282
HFDL03
HFDL07
HFDL01
HFDL04
HFDL02
HFDL
NAT-D
NAT-C
NAT-B
NAT-A
NAT-F
NAT-E
NAT-C
NAT-B
NAT-A
SAT-2
SAT-1
AFI-1
AFI-2
CEP-1/2/3
CAR
CWP
SP
NP

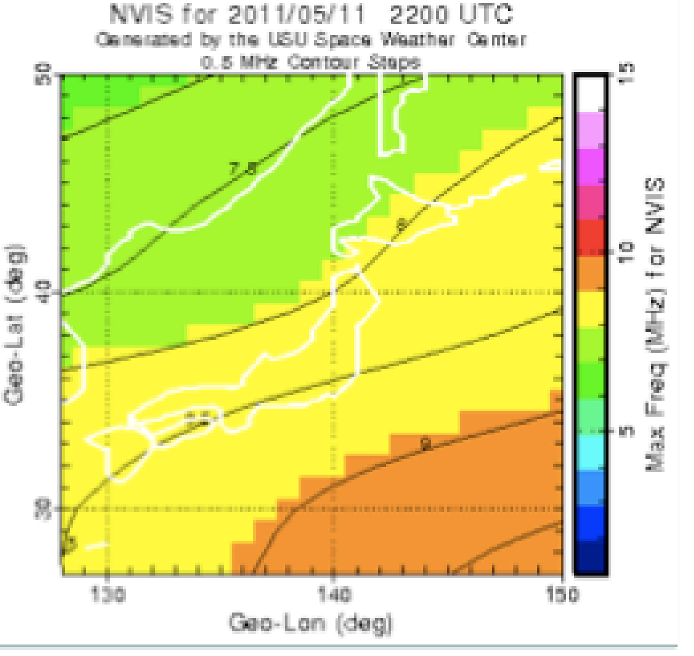
# Examples of USU GAIM HF Capabilities

# Space Weather Center

## How SWC helps emergency responders

- Frequencies to transmit over nearby mountains.
- 3-hour forecast of frequencies.
- Recommendation of available frequencies to global operators.
- Available HF frequencies for Emergency Responders



# Katrina First Responders Were Affected

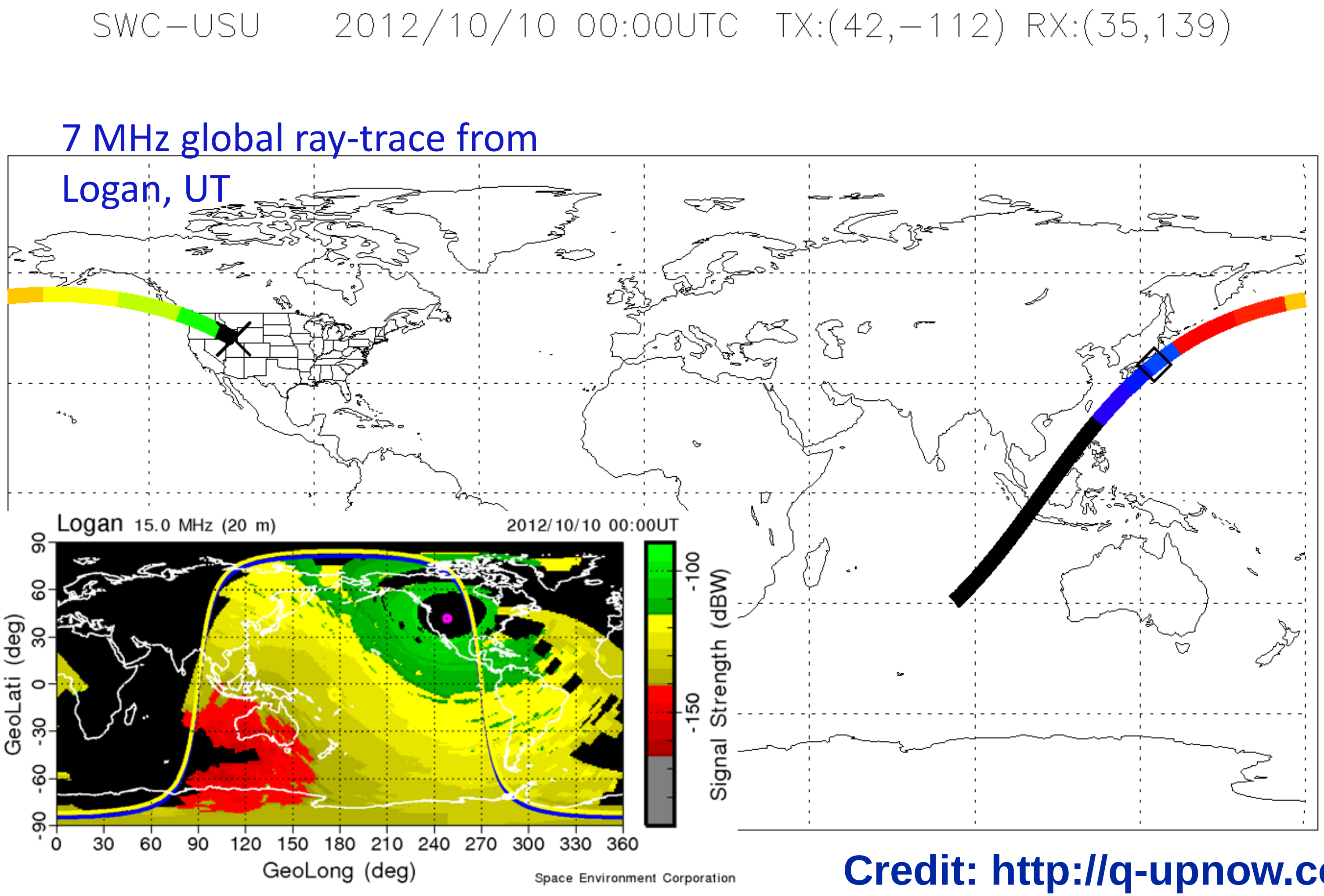

On September 7, 2005, a large solar flare erupted that affected HF communications.

U.S. disaster relief workers lost the reliability of their back-up communication system.

# 1. HF Communications Support

- SWC combines models and utilities to provide HF propagation information
  - GAIM Ionosphere
  - ABBYNORMAL D-Region absorption maps
  - HASEL Ray-Tracing Model
  - Great Circle Signal Strength (GCSS)
  - Near Vertical Incidence Skywave (NVIS)

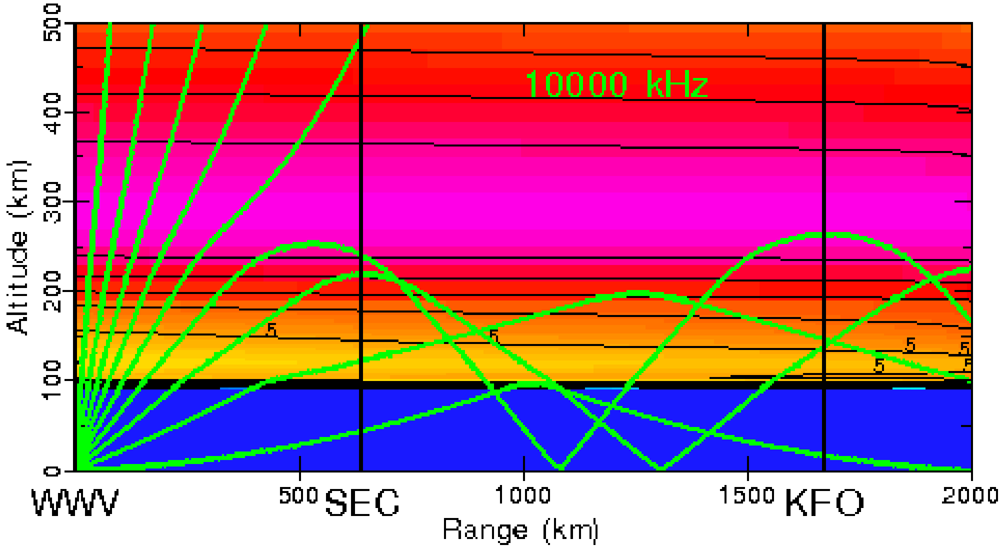
# Propagation




**Credit: http://q-upnow.com**

# Great Circle Signal Strength (GCSS)
## for point-to-point HF COMM

- GCSS code combines a number models for HF Communications modeling
  - USU's GM-GAIM global ionosphere
  - SEC's ABBYNORMAL Data-Driven D Region
  - Chris Coleman's HASEL Ray Tracing Code
  - SEC's ABSS Absorption and Signal Strength Module

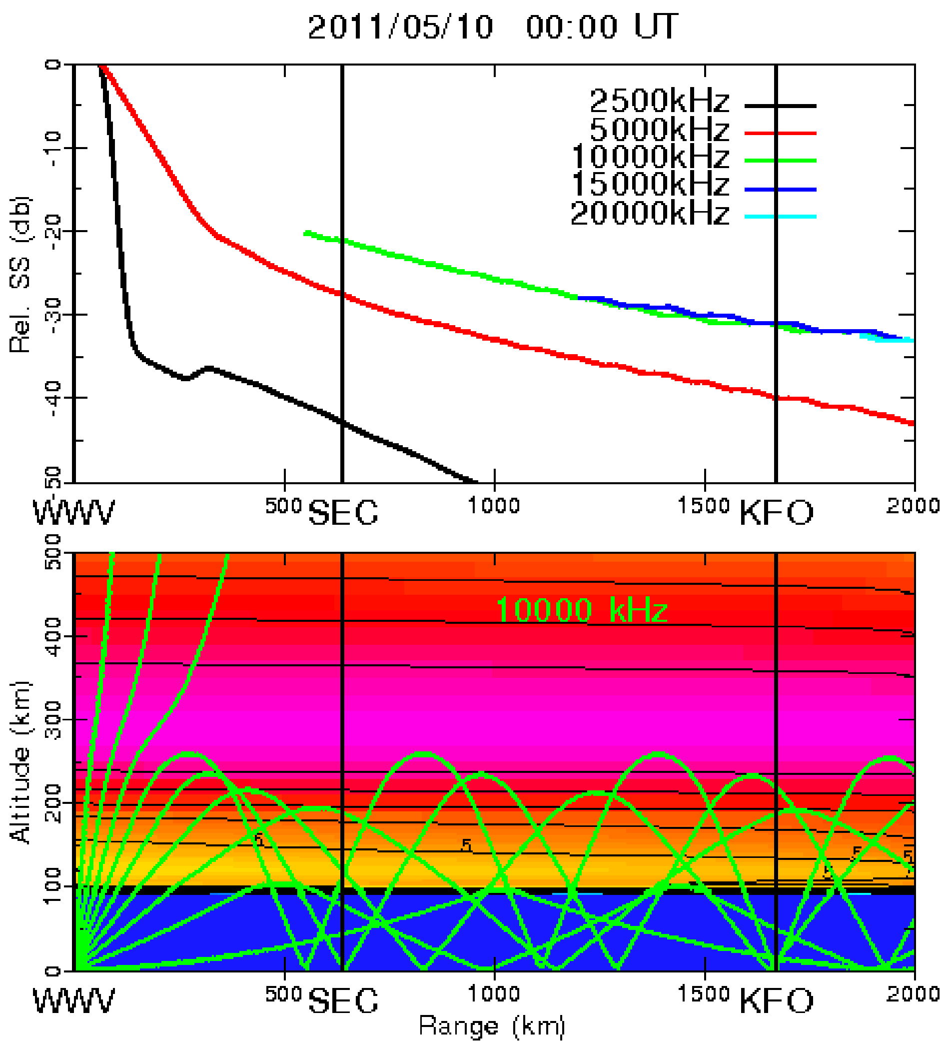


# GCSS Calculates HF Signal Strength
## (Range from Single Transmitter)

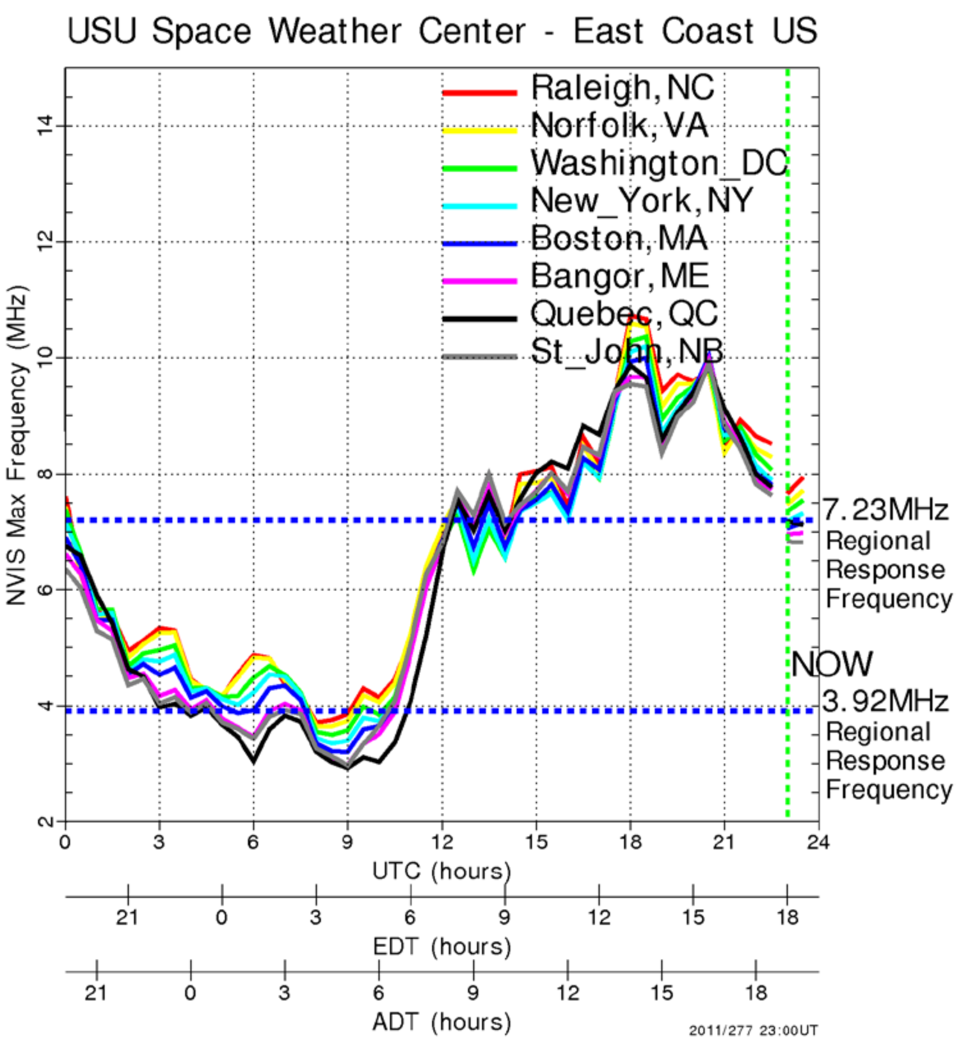
- Produces Signal Strength (SS) for multiple HF frequencies.
- Example shows SS along distance from the transmitter (WWV)
- Includes skywave reflection and signal loss due to a number of processes:
  - D region absorption
  - spatial geometries
  - ground reflection

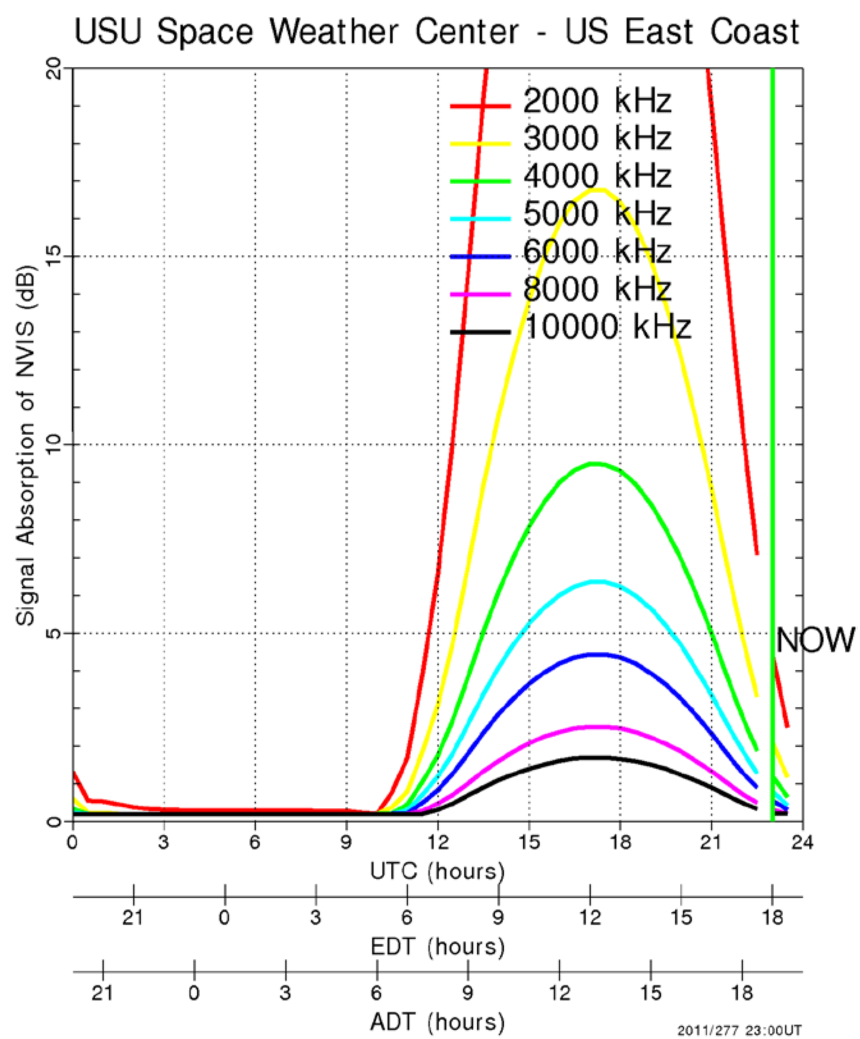
F-Region

E-Region
D-Region



# HF frequencies Oct 4, 2011



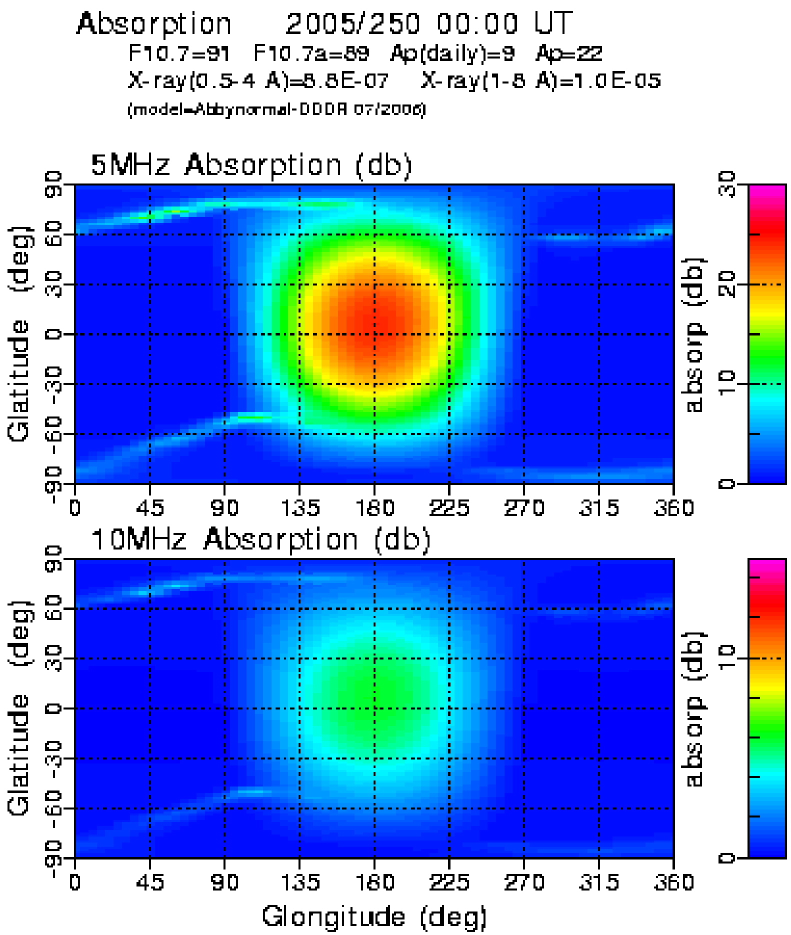




**Credit: USU SWC**

# ABBYNORMAL*

## Data-Driven D-Region Model

Solar Flare Day



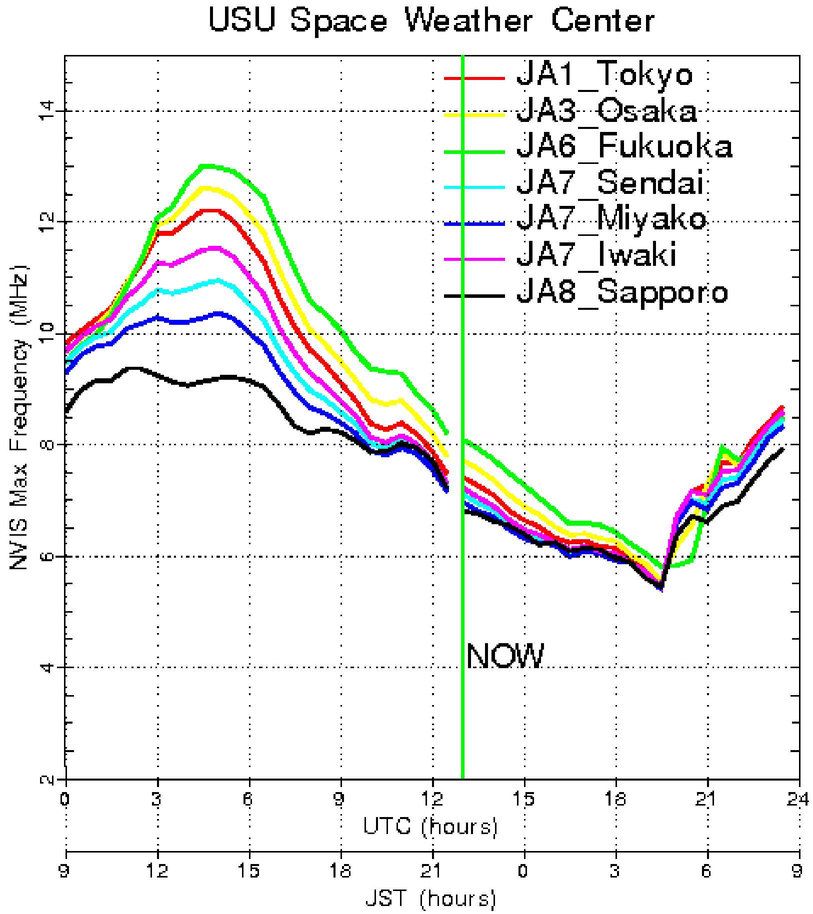

- Global D-Region electron densities from 40 to 130 km.
- Calculates signal absorption for HF propagation codes.

*ABsorption BY the D and E Region of HF Signals with NORMAL Incidence

# Near Vertical Incidence Skywave for Japan

- **SWC HF communications for Japan emergency conditions**

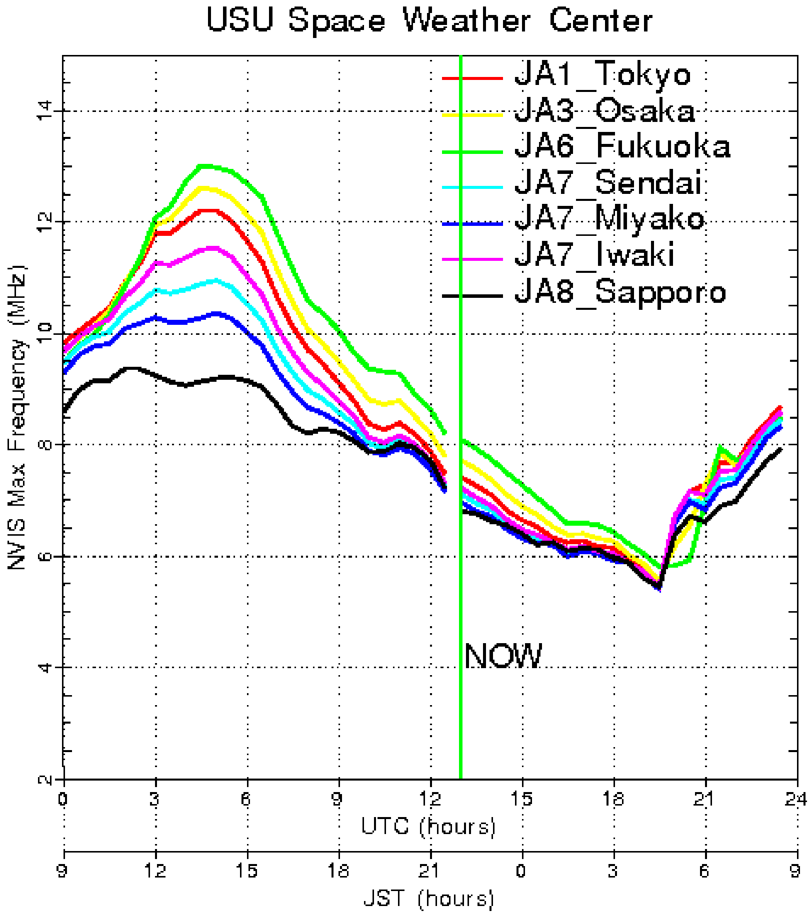
## Maximum Frequency (MHz) for Near Vertical Incidence Skywave



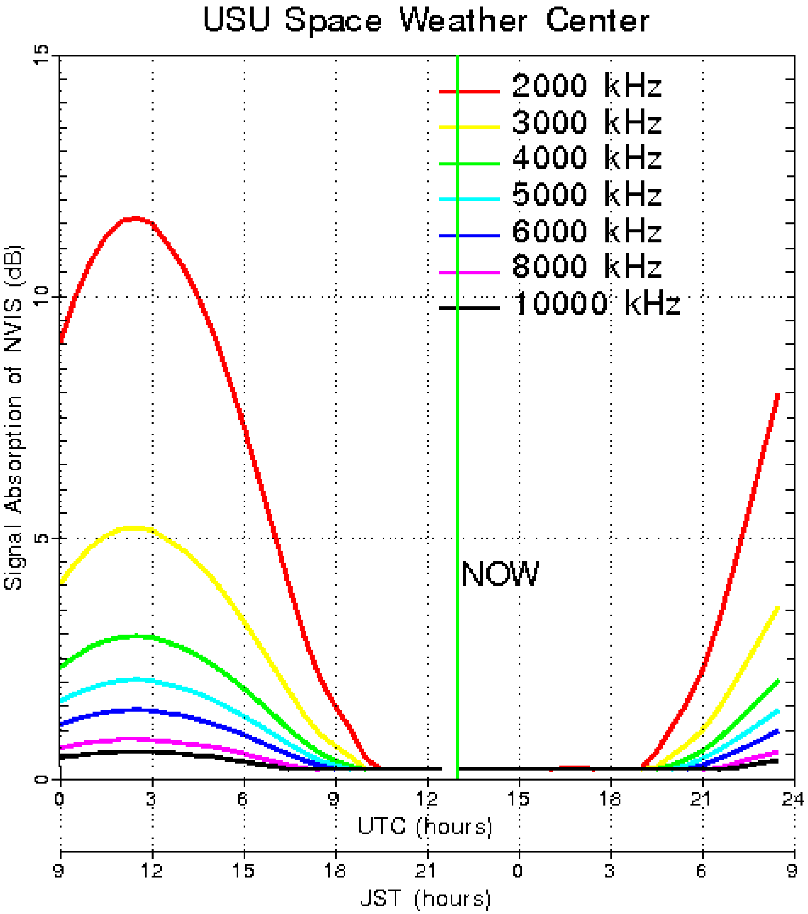
# NVIS for Japan

- **SWC HF communications for Japan emergency conditions**

**Maximum Frequency (MHz) for Near Vertical Incidence Skywave**




**Signal Strength Absorption of NVIS HF Communication**



# Global HF Comm for Japan

**3.5 MHz Signal Strength**

**14.1 MHz Signal Strength**