

# A Survey of Terrestrial Radio Research Techniques

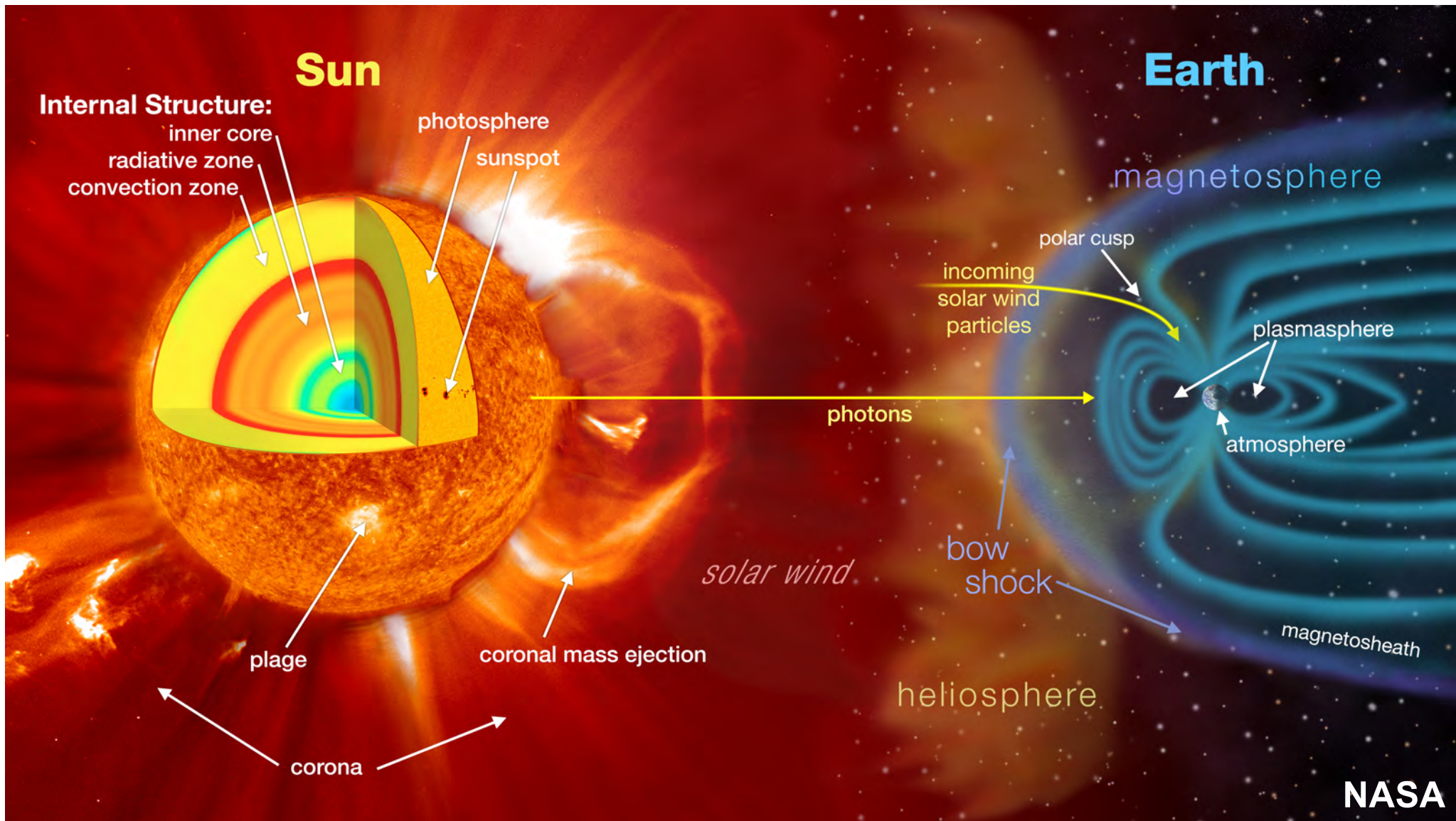
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**Nathaniel A. Frissell**

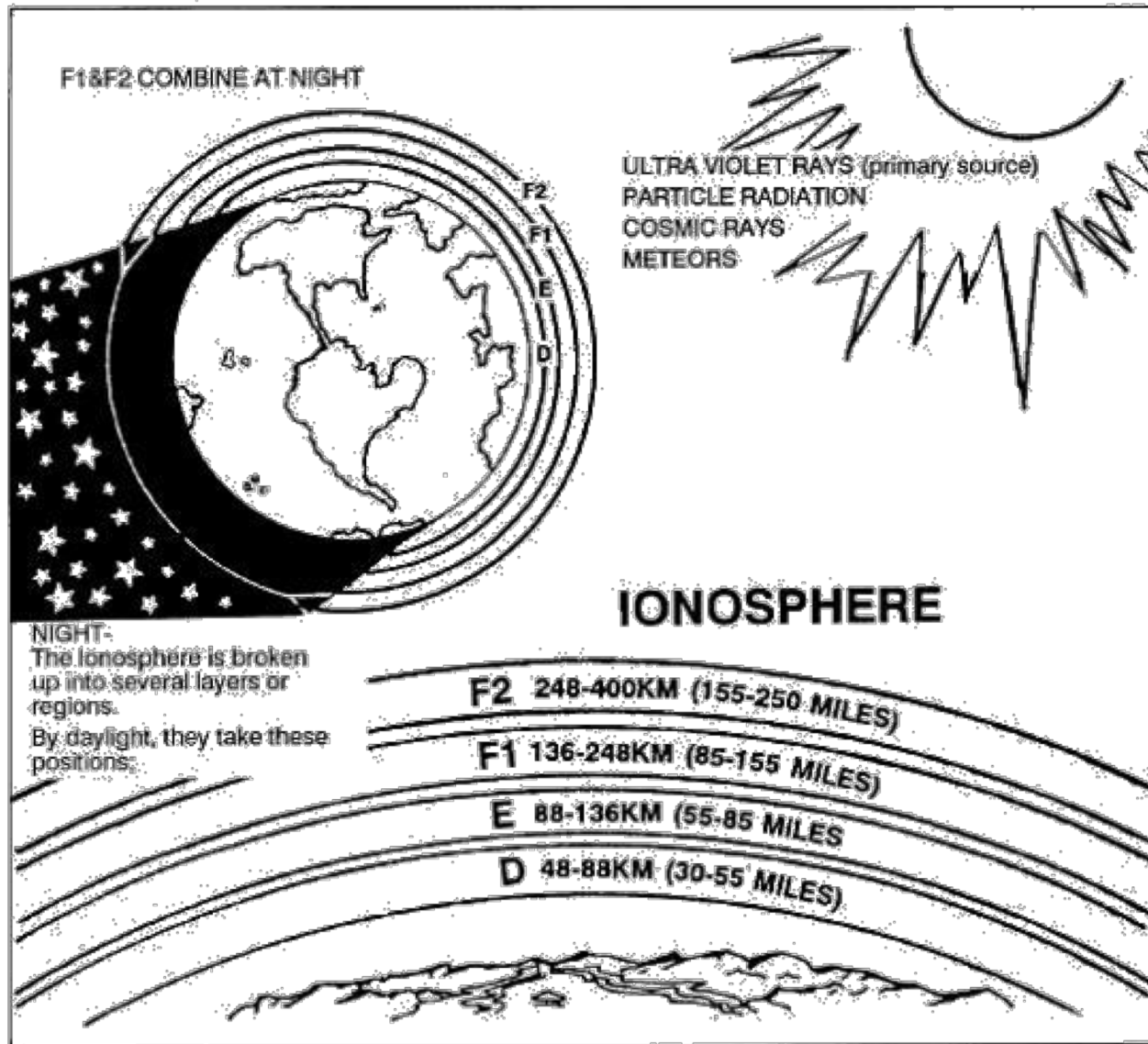
Assistant Research Professor

New Jersey Institute of Technology

# Solar-Terrestrial Environment

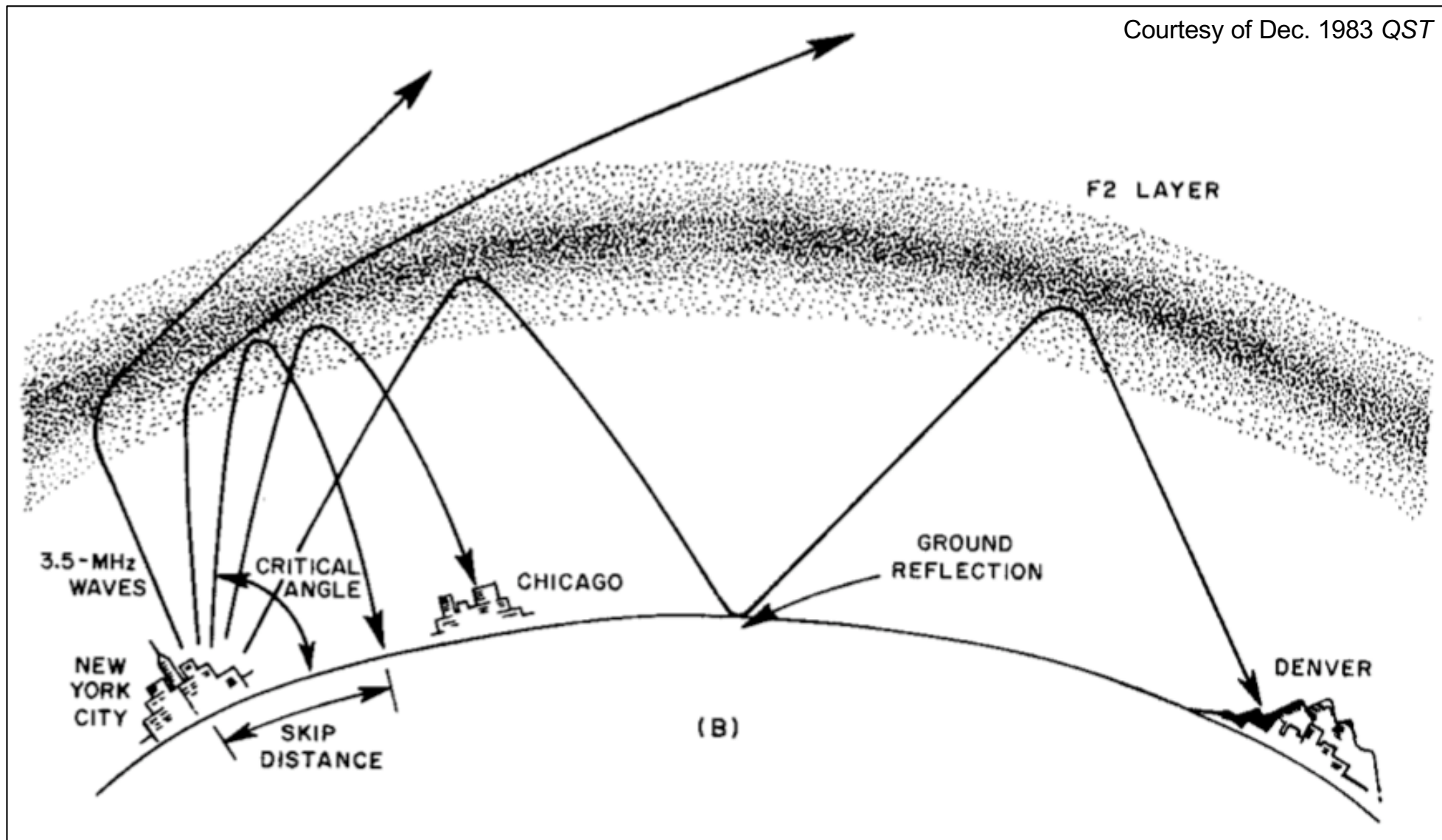


# Ionosphere



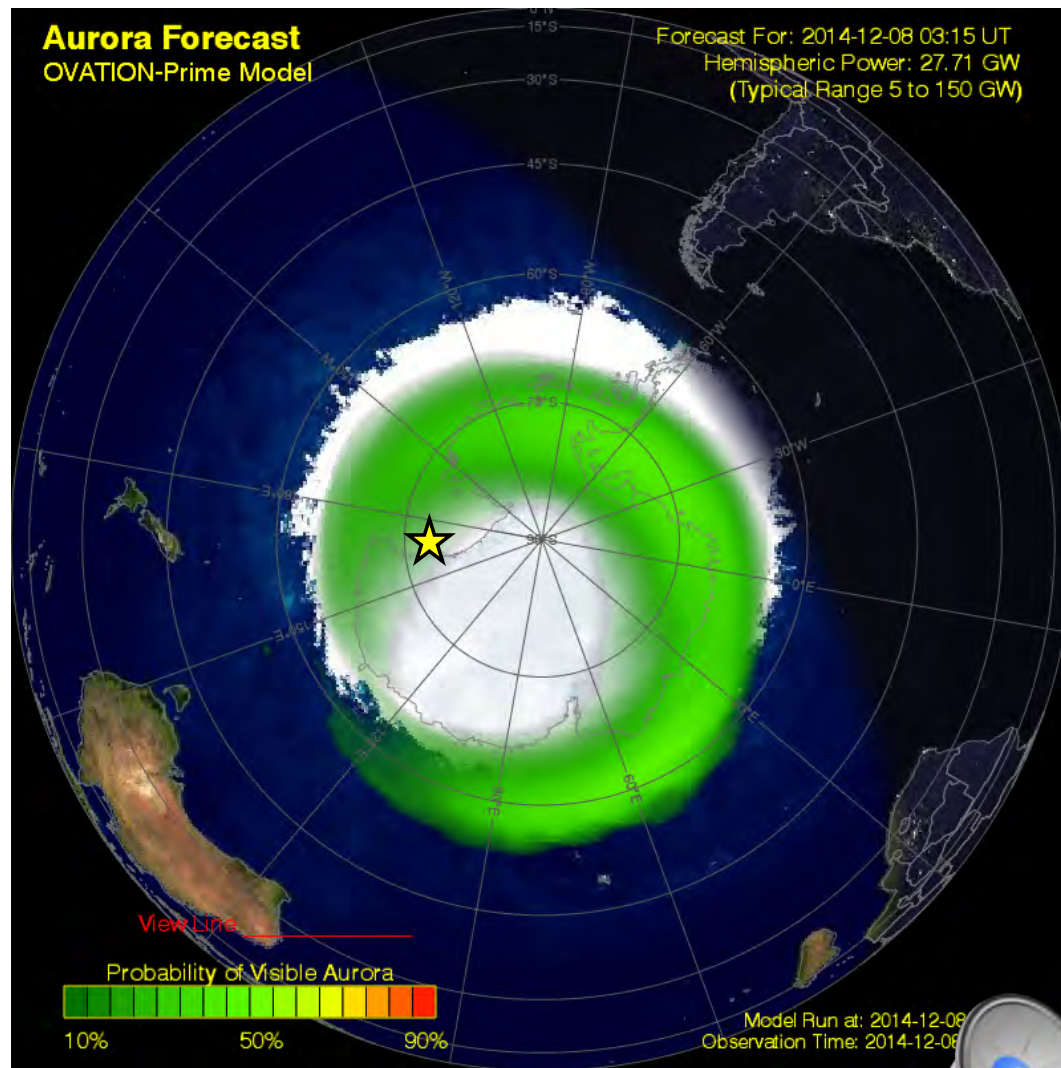
# Skip Propagation

Courtesy of Dec. 1983 QST



# Space Weather and Ham Radio

McMurdo Station, Antarctica  
KC4USV



20141227 0746 UT Aurora @ KC4USV 14010 kHz

# Ionospheric Radio Instruments

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- Ionosondes
- Riometers
- GPS Total Electron Content (GPS-TEC)
- GPS Scintillation Receivers
- Incoherent Scatter Radars
- SuperDARN Radars
- Ionospheric Heaters
- Signals of Opportunity

# Ionospheric Radio Wave Propagation

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# The Plasma Frequency

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If the electrons in a plasma are perturbed (assuming the ions are much more massive, so they remain stationary), the electrons oscillate about their equilibrium position at frequency known as the plasma frequency.

$$f_p = \sqrt{\frac{n_e e^2}{2\pi m_e \epsilon_0}} \approx 9 n_e^{1/2} \text{ kHz} \quad (n_e \text{ in cm}^{-3})$$

So if  $n_e = 10^6 \text{ cm}^{-3}$ ,  $f_p = 9 \text{ MHz}$



# Electromagnetic Waves in a Plasma

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An electromagnetic wave can only propagate through a plasma if its frequency is greater than the local plasma frequency; then a wave packet or signal travels at the group velocity given by:

$$v_{gp} = c \sqrt{1 - \left( \frac{f_p}{f_{wave}} \right)^2} \leq c = \text{the speed of light}$$

The total delay in a signal is proportional to the column number density of electrons along the signal path – the total electron content or TEC

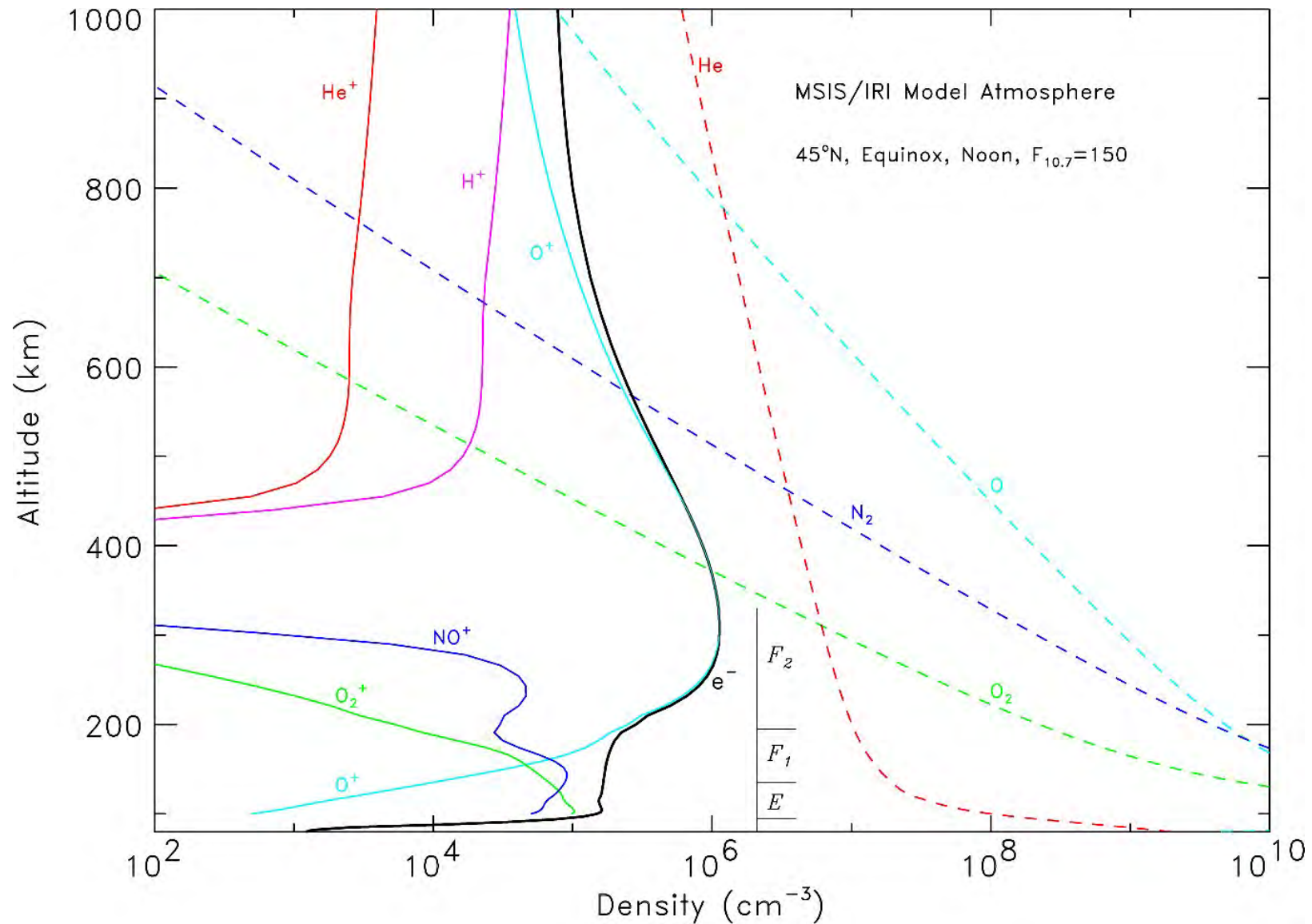
# Reflection of Radio Waves

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If an electromagnetic wave propagates into a plasma with increasing plasma density, its group velocity will get progressively slower as the plasma frequency increases to near the wave frequency. The wave will reflect at the point where the wave frequency equals the plasma frequency, i.e. where

$$f_{wave} = f_p = \sqrt{\frac{n_e e^2}{2\pi m_e \epsilon_0}} ; 9n_e^{1/2} kHz \quad (n_e \text{ in cm}^{-3})$$

# Thermospheric/Ionospheric Densities



# Ionosondes

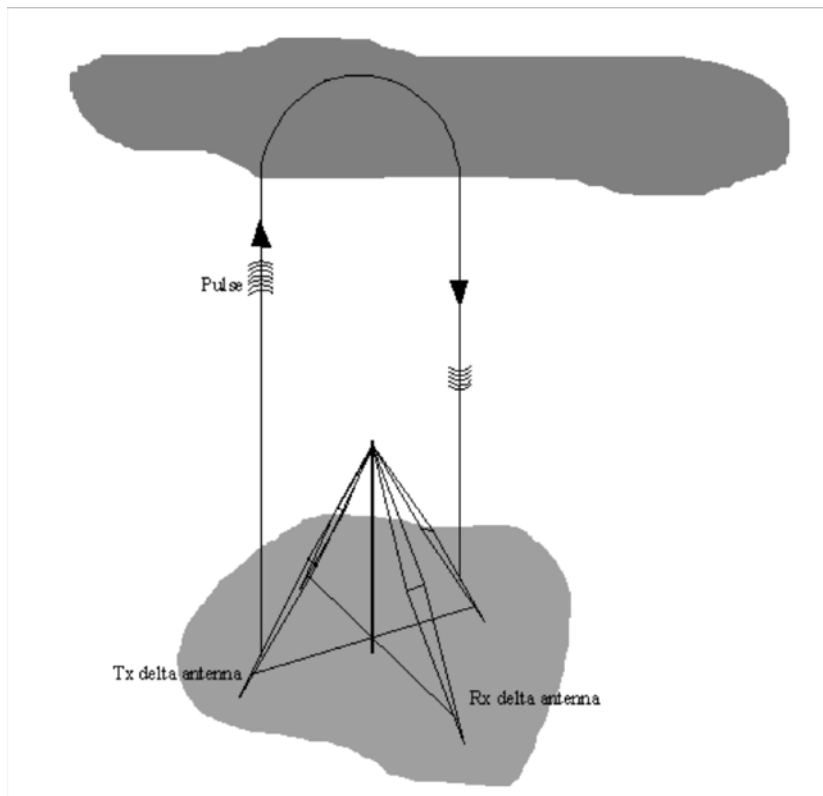
**San Juan Observatory  
(Small – 15 m tall x 45 m long)**



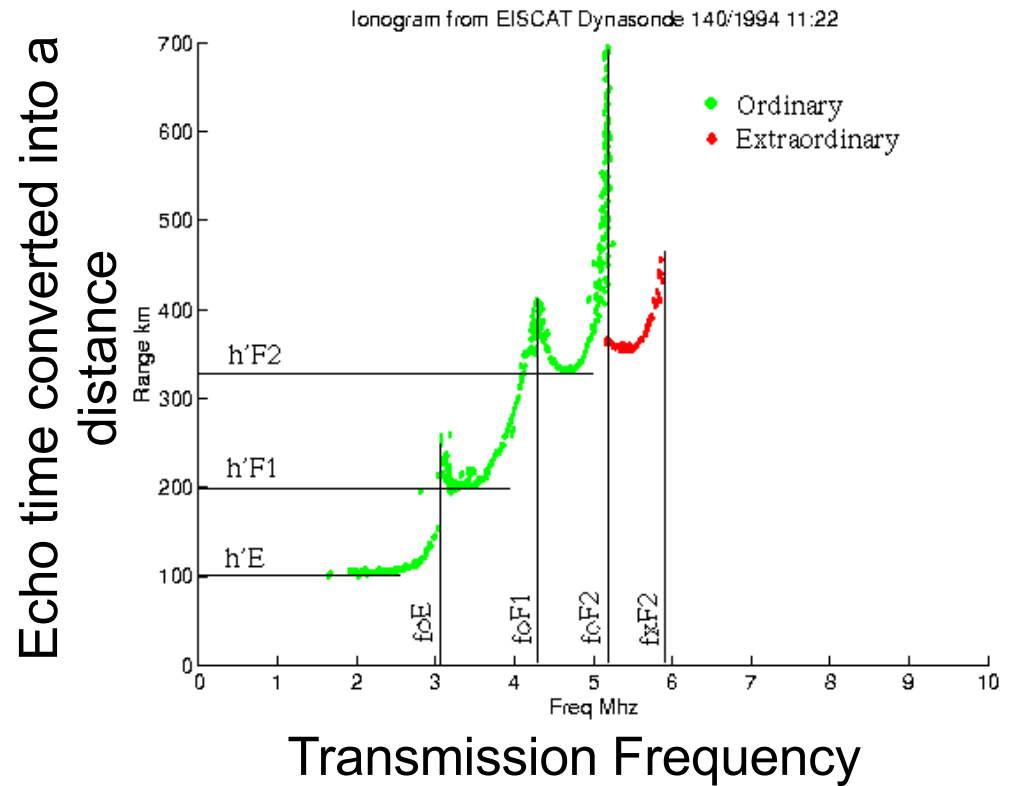
[Dr. Terry Bullett, W0ASP, U of Colorado]

# Ionosondes & Ionograms

*Principle of an  
“ionosonde”*

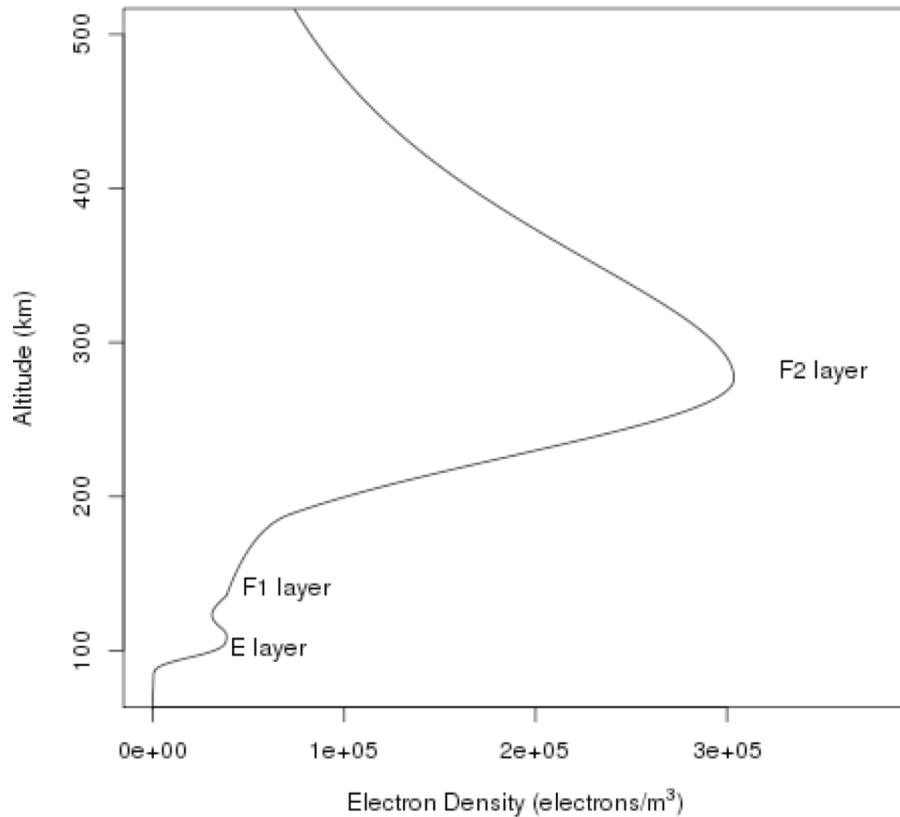


*an “ionogram”*

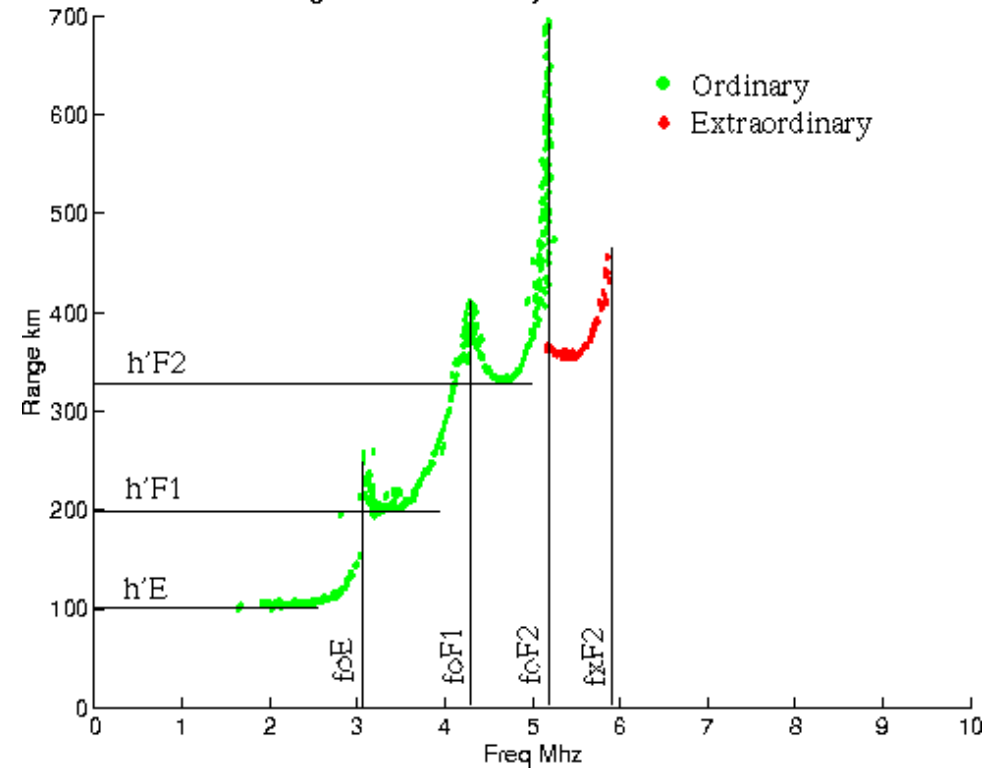


# Electron Profile vs. Ionogram

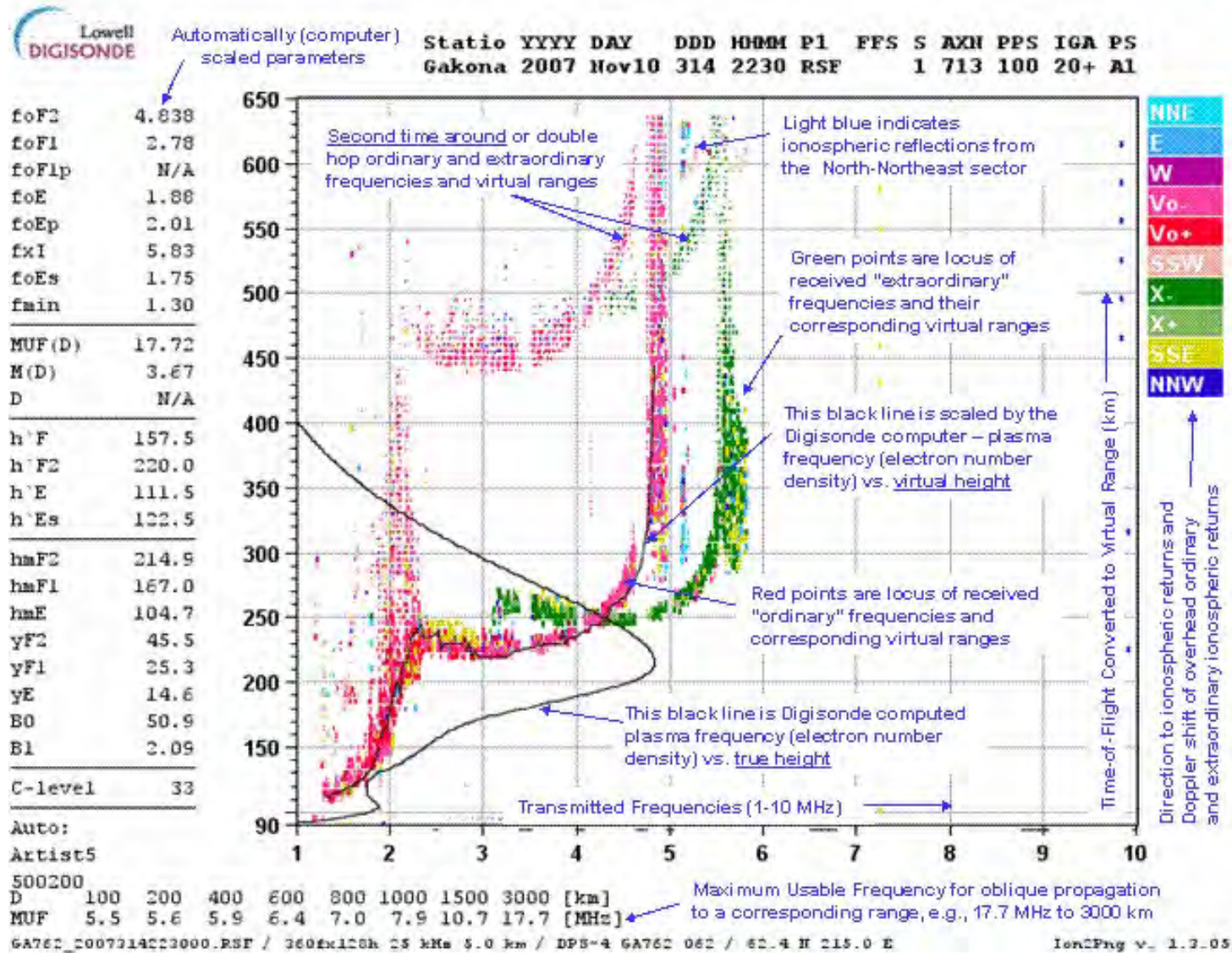
Idealised Ionospheric Profile



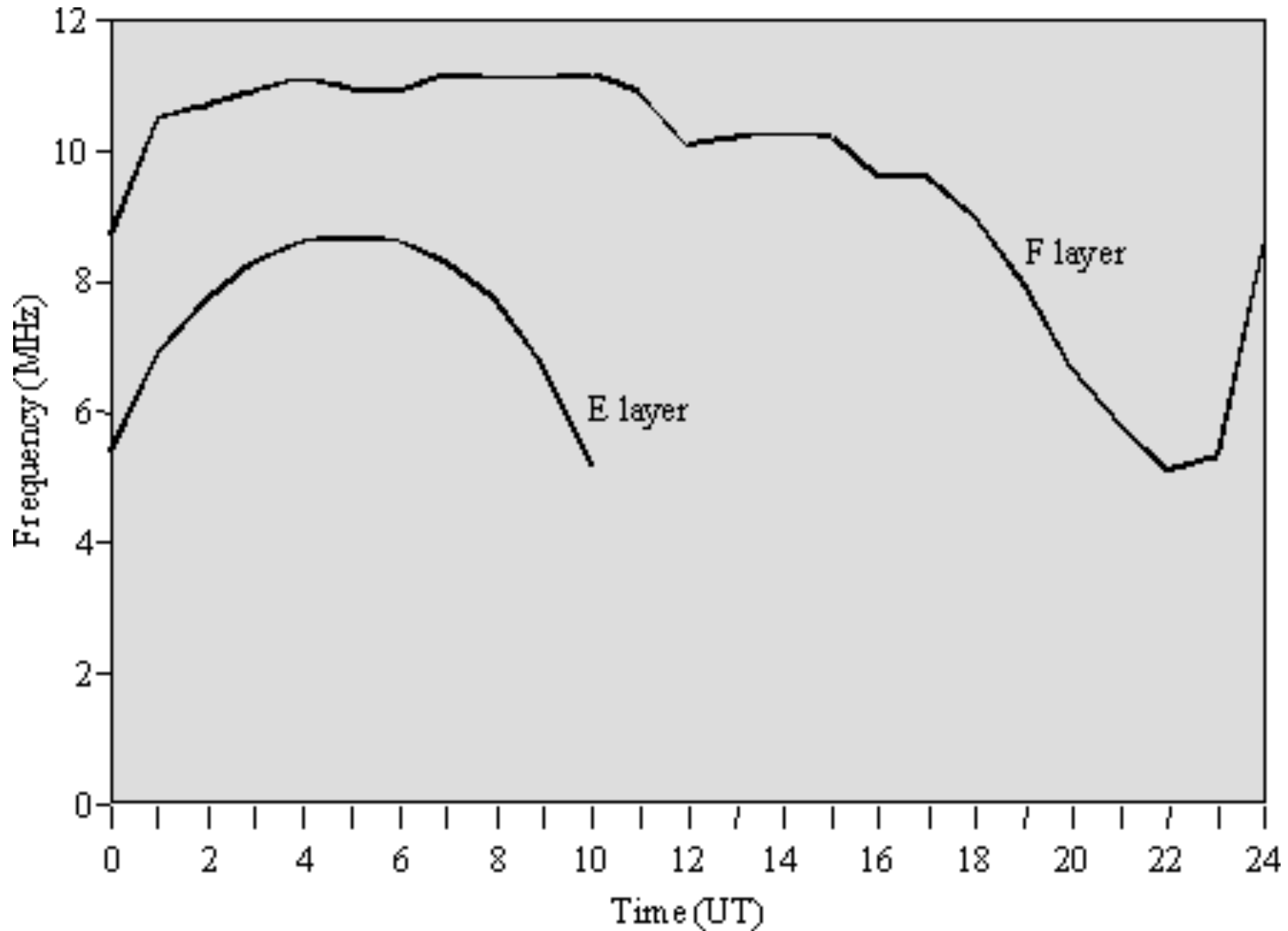
Ionogram from EISCAT Dynasonde 140°1994 11:22



# Modern Digital Ionogram (Gakona, AK)



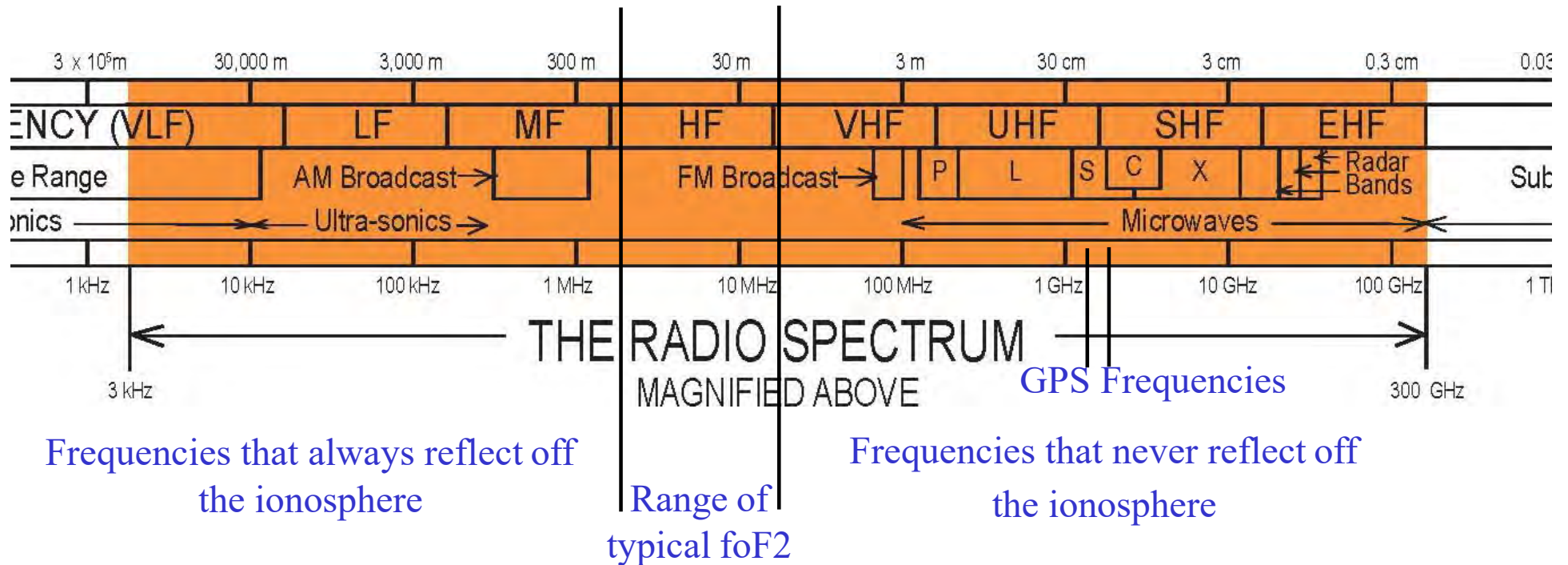
# E & F Layer Diurnal Variation



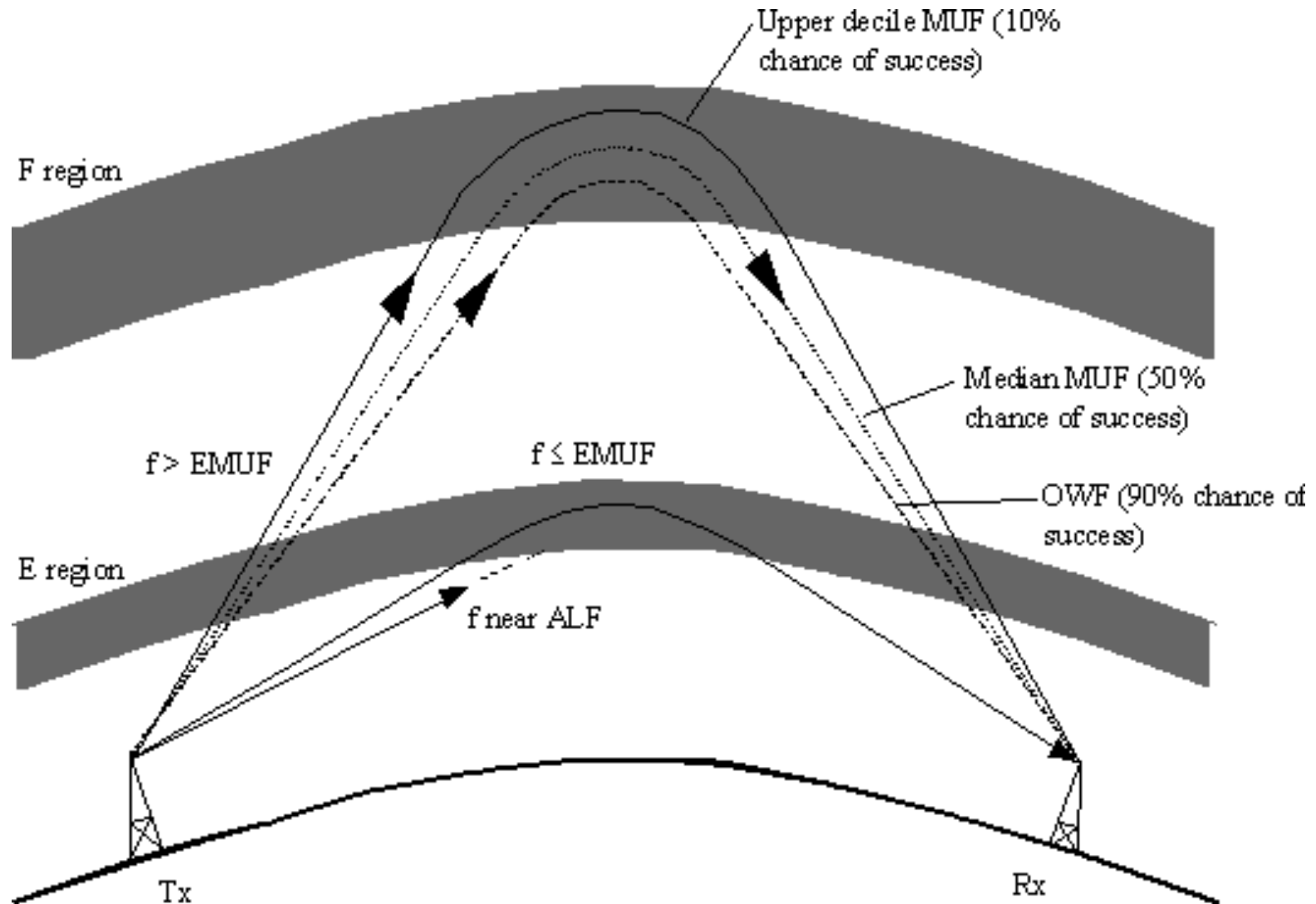
The source of this material is at <http://www.ips.gov.au/>



# Radio Waves and the Ionosphere



# Maximum Usable Frequency (MUF)

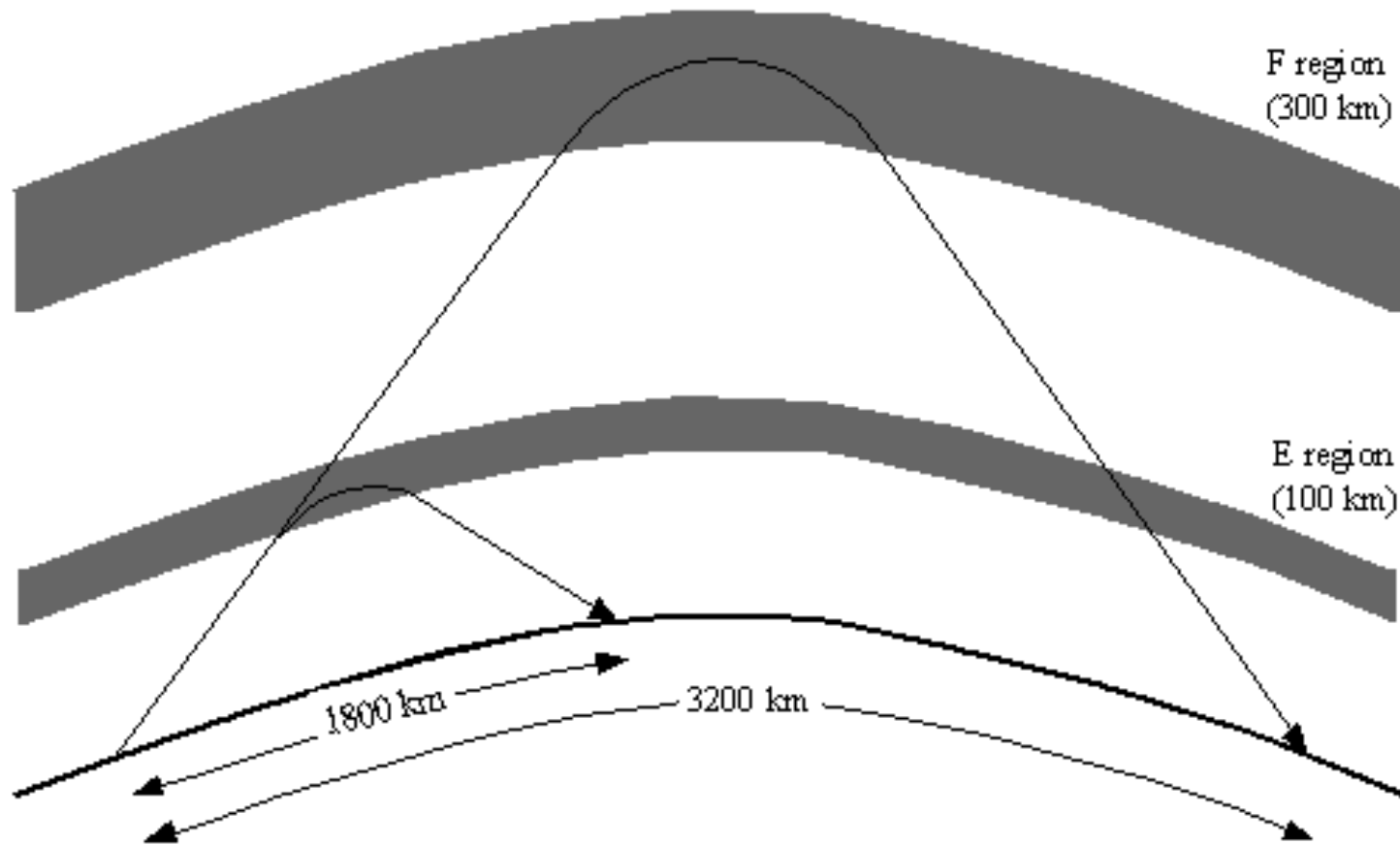


The source of this material is at <http://www.ips.gov.au/>

ALF = Absorption Limiting Frequency, OWF = Optimum Working Frequency

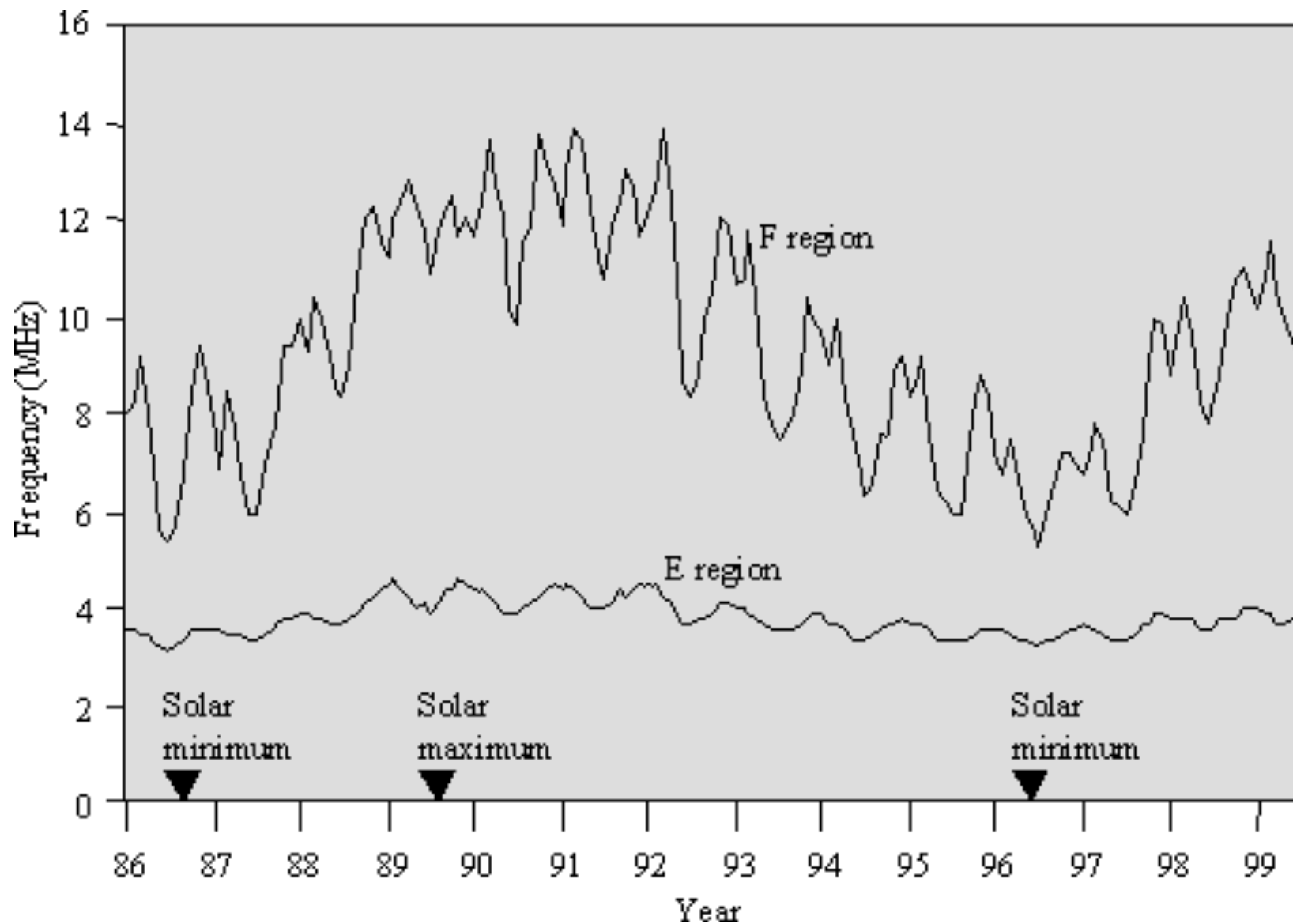
# Hop Length

“Hop Length” depends on frequency and reflection height

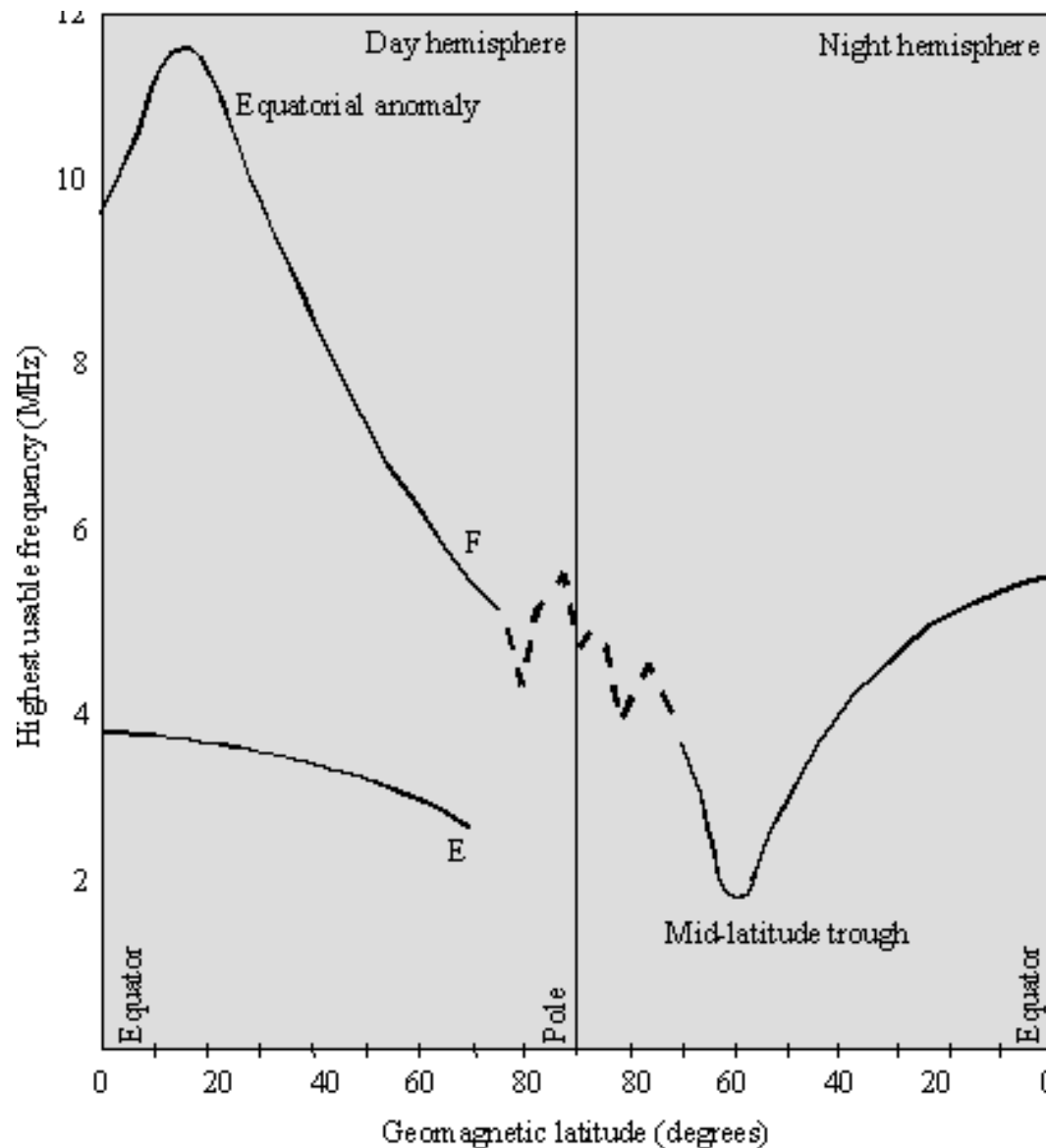


The source of this material is at <http://www.ips.gov.au/>

# Ionospheric Frequencies Over a Solar Cycle



# Diurnal and Latitudinal Dependence



**E and F-region reflecting frequencies depend upon magnetic latitude differently from day to night**

# Four Ways by which Space Weather affects Radio Communications

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Affect GPS Signals

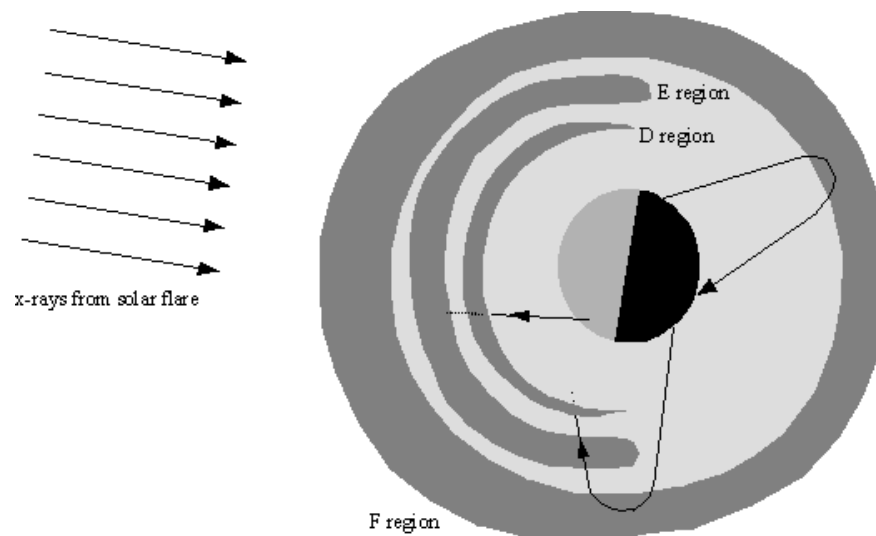
- **Radio Absorption:** signals in the **HF band (Short Wave)** can be absorbed (attenuated) by additional ionization in the lower ionosphere caused by solar X-rays (sunlit ionosphere) or energetic particles (SEP) (high latitudes)
- **Scintillations:** Naturally occurring instabilities in the ionosphere (sporadic-E, spread-F) can scatter and phase-mix signals causing loss of signal
- **Masking:** Naturally generated solar radio waves can mask man-made signals
- **Phase and Group Delay:** Introduces range errors
- All effects on radio communication depend upon frequency of wave and wave path

# HF Absorption

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# HF Radio Absorption

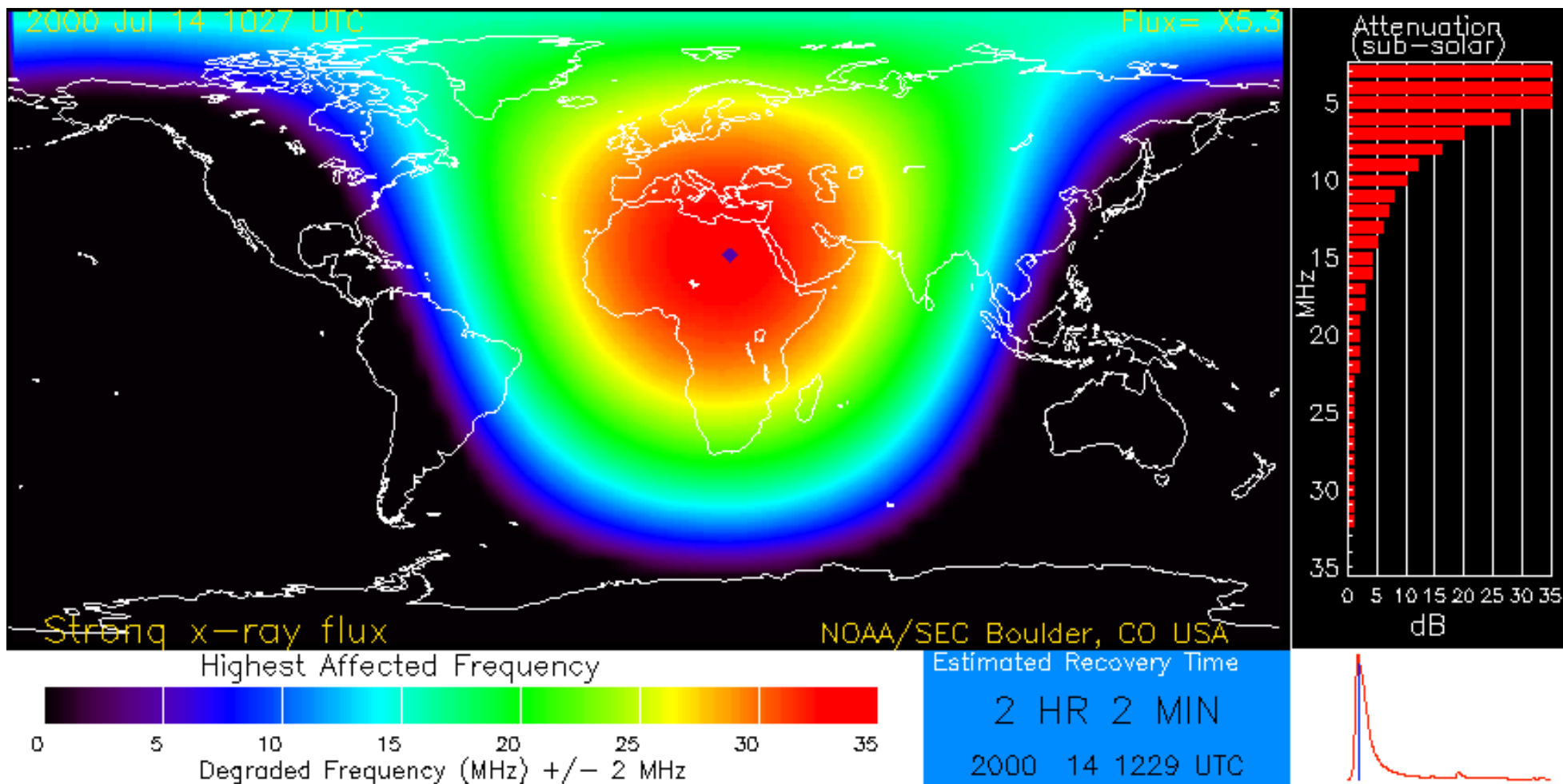
Short wave fade-outs (SWEs) also called daylight fade-outs or sudden ionospheric disturbances (SIDs). Solar radiation, either **X-rays** from large solar flares (dayside) or **SEP** (polar regions) cause increase ionization in the D region which results in greater absorption of HF radio waves. If the event is large enough, the whole of the HF spectrum can be rendered unusable for a period of time. Flares, and hence fade-outs are more likely to occur around solar maximum and in the first part of the decline to solar minimum.



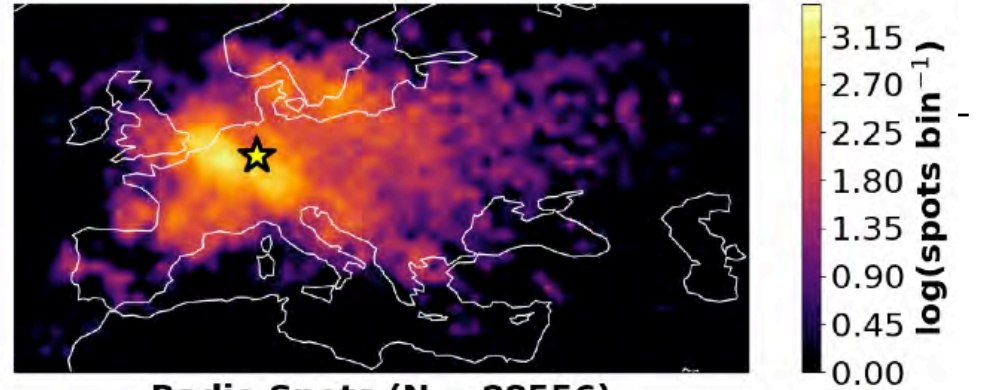


# NOAA D-RAP

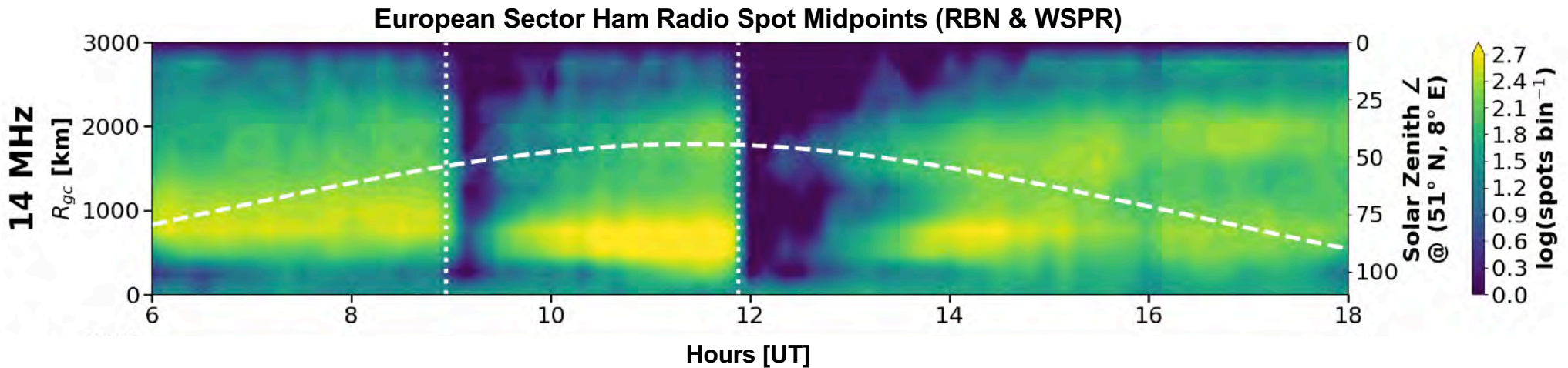
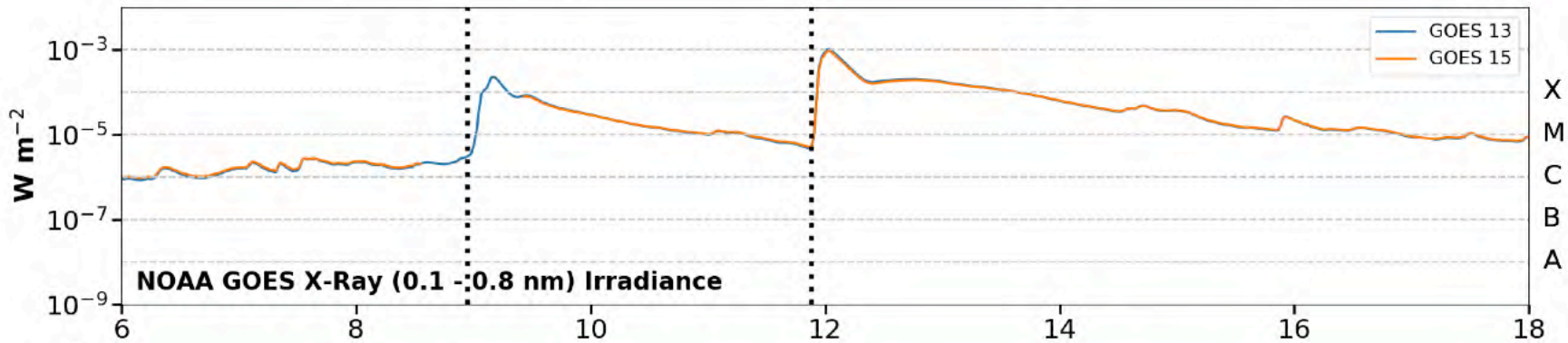
NOAA/SEC D-Region Absorption Prediction  
Bastille Day X-ray event: 2000 Jul 14 1230 UTC



# Solar Flare

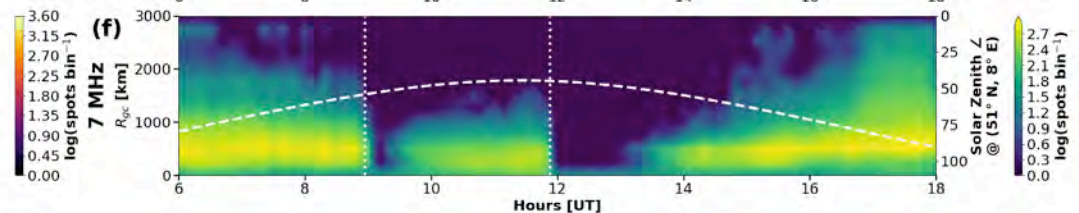
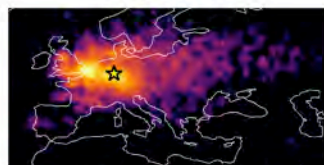
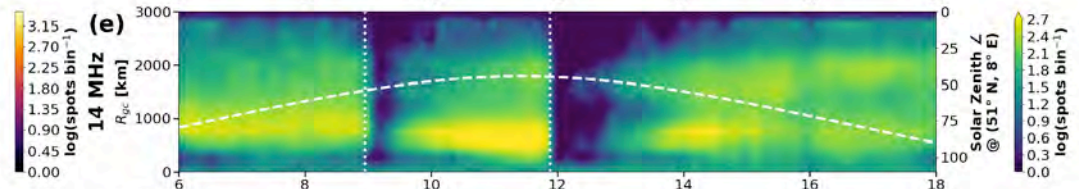
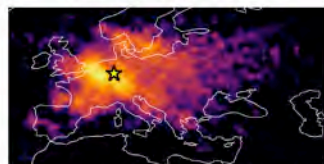
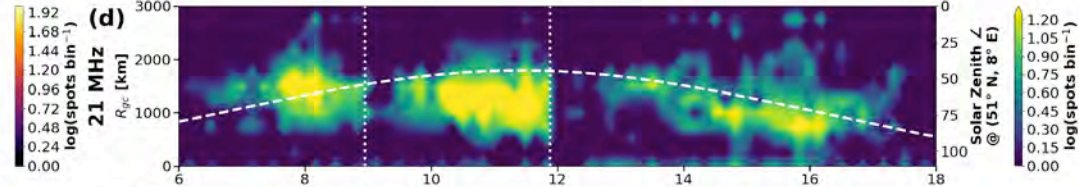
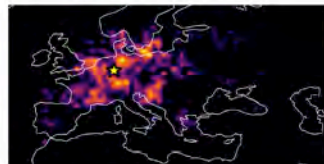
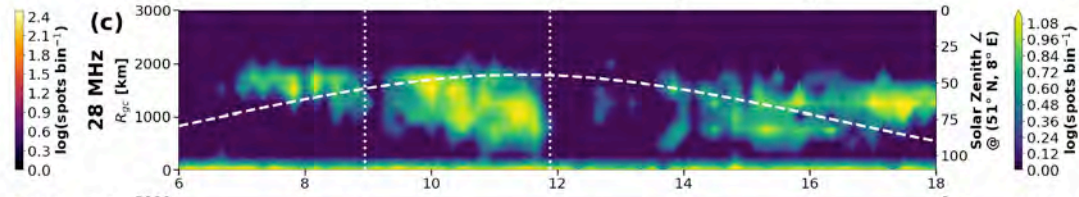
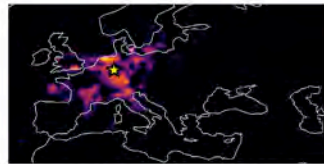
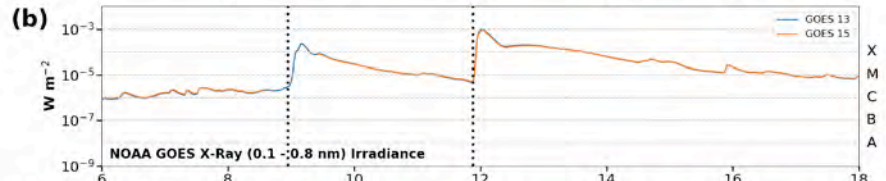
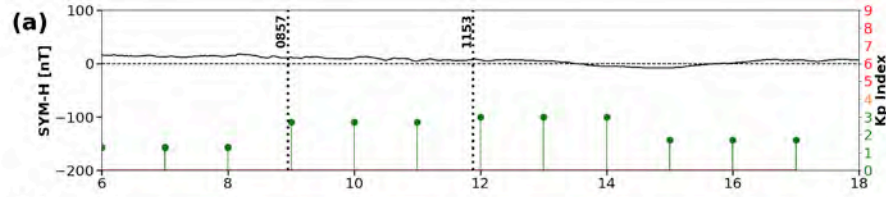


6 September 2017



# Solar Flare

06 Sep 2017  
 Ham Radio Networks  
 N Spots = 185579  
 RBN: 14%  
 WSPRNet: 86%



# Riometer

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- **Relative Ionospheric Opacity Meter**
- Directly measures absorption of cosmic rays
- Indirectly measures electron density, particle precipitation
- Typically passive instrument 30-50 MHz



IRIS - Imaging Riometer for Ionospheric Studies in Finland  
(<http://kaira.sgo.fi/>)

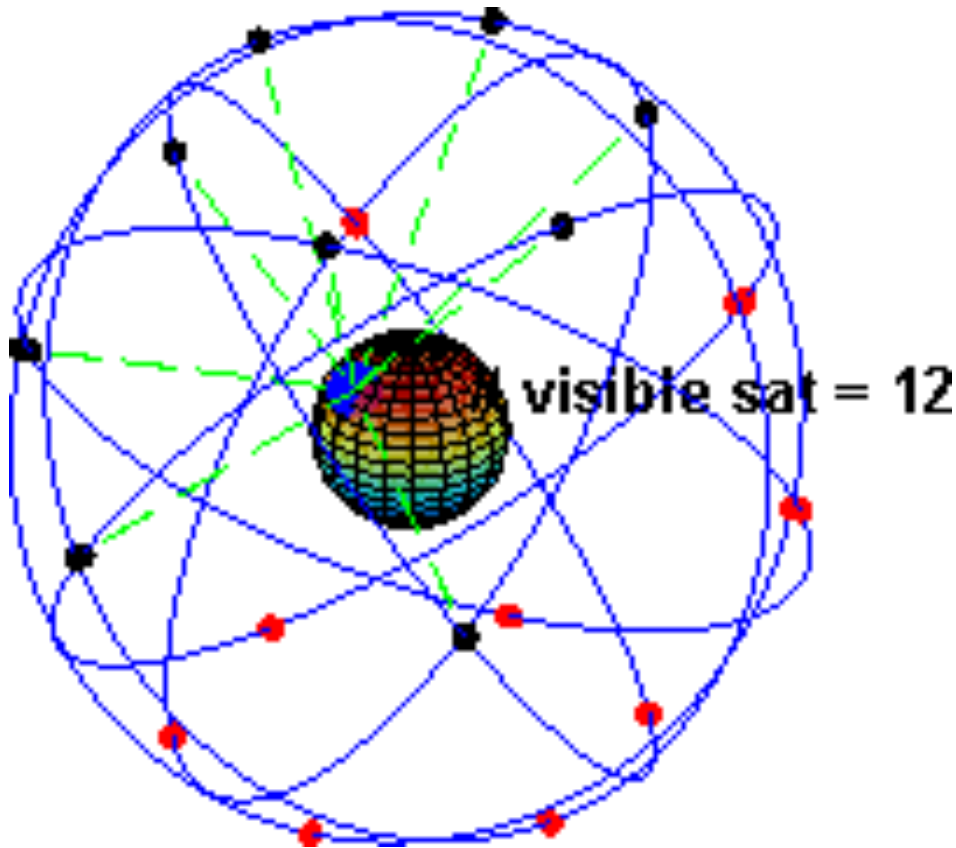
Photo: Derek McKay

# GNSS and the Ionosphere

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# GPS Navigation and Positioning System

- Currently 29 satellites in orbit in 6 orbital planes
- Transmit coded signal at two frequencies: 1227 and 1575 MHz
- Need signals from 4 satellites to give time and fix location.



# Operational and Planned Global Navigation Satellite Systems (GNSS)

| System                     | GPS   | GLONASS                              | BeiDou/<br>COMPASS   | Galileo   | NAVIC  | QZSS   |
|----------------------------|---|--------------------------------------|--|---|--|--|
| Owner                      | United States                                     | Russia                               | China  | EU  | India  | Japan  |
| Coverage                   | Global  | Global                               | Regional<br>(Global by 2020)                                     | Global  | Regional   | Regional                                       |
| Orbital altitude           | 20,180 km   | 19,130 km                            | 21,150 km  | 23,222 km   | 36,000 km  | 32,000 km                                      |
| Total Number of satellites | 31 (at least 24 by design)                        | 28 (at least 24 by design)           | 5 geostationary orbit (GEO)<br>30 medium Earth orbit (MEO)       | 18 satellites in orbit,<br>30 operational satellites budgeted   | 3 geostationary orbit (GEO)<br>5 geosynchronous (GSO) medium Earth orbit | 4 in elliptical inclined geosynchronous orbits |
| Frequencies                | 1.57542 GHz (L1 signal)<br>1.2276 GHz (L2 signal) | Around 1.602 GHz<br>Around 1.246 GHz | 1.561098 GHz<br>1.589742 GHz<br>1.20714 GHz<br>1.26852 GHz       | 1.164-1.215 GHz<br>1.260-1.300 GHz<br>1.559-1.592 GHz           | 1.1765 GHz<br>2.4920 GHz   |  |
| Status                     | Operational                                       | Operational                          | 22 satellites operational,<br>40 additional satellites 2016-2020 | 18 satellites operational<br>12 additional satellites 2017-2020 | 6 satellites fully operational,<br>IRNSS-1A partially operational        | 4 satellites system Operational in 2018        |

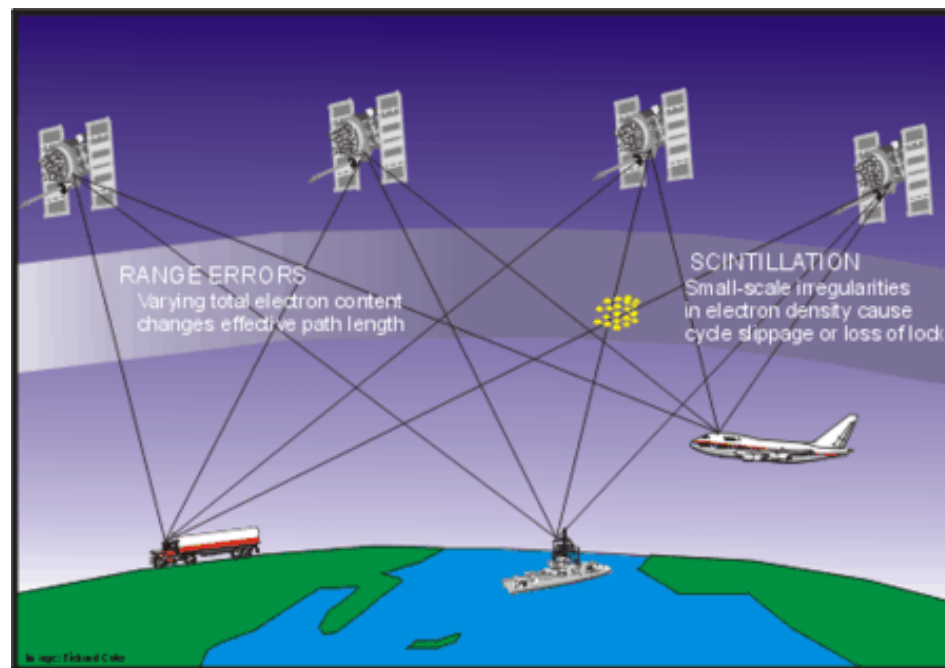
# Ionospheric Effects on GPS

## • TEC

- Induces Range Errors
- Highly variable with location, time, season, magnetic and solar activity

## • Scintillation

- Induces rapid changes in amplitude and phase of incoming signal
- Can induce cycle slips and loss of lock that degrade performance



## • Masking

- Naturally generated solar radio waves overpowers GPS signal so it can't be received

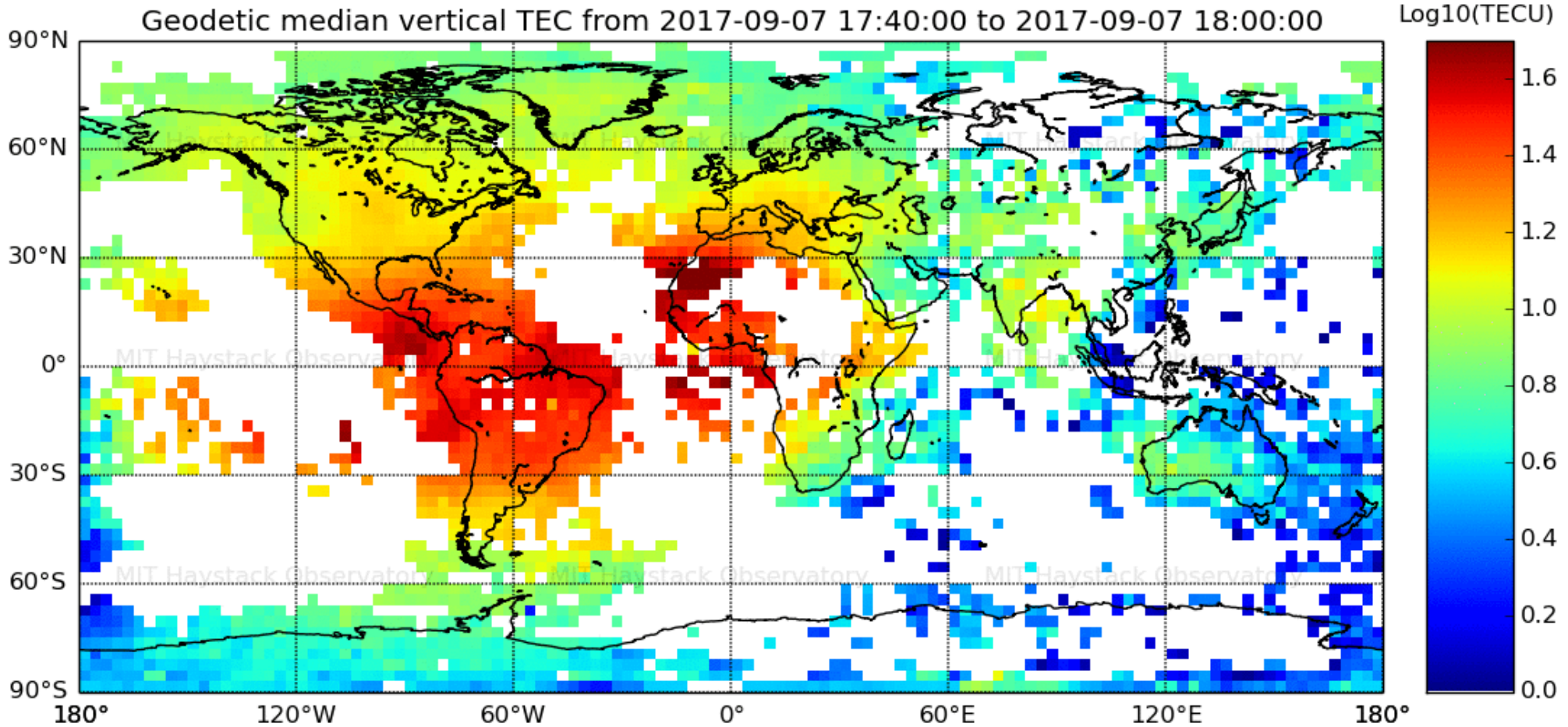


# Total Electron Content (TEC)

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- Group delay in radio signal is proportional to the integral of electron density along the wave path.
- With signals at two frequencies, difference in arrival time can be used to calculate TEC and hence remove effect.
- Sharp spatial gradients in TEC, such as are generated during geomagnetic storms can cause significant errors.

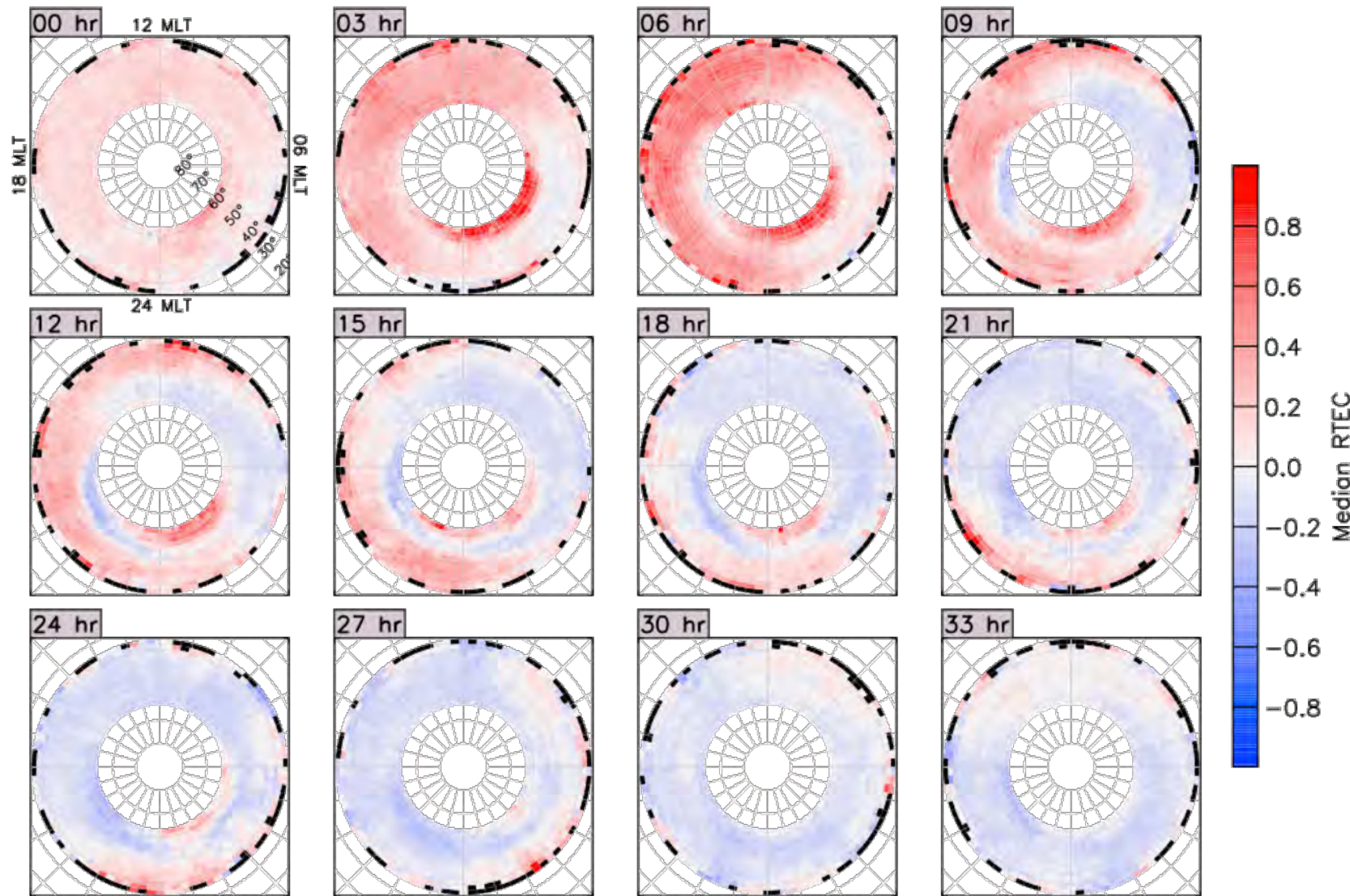
# Global TEC Maps



© 2017 MIT Haystack Observatory

© MIT Haystack Observatory / Anthea Coster

# Ionospheric Storm Response



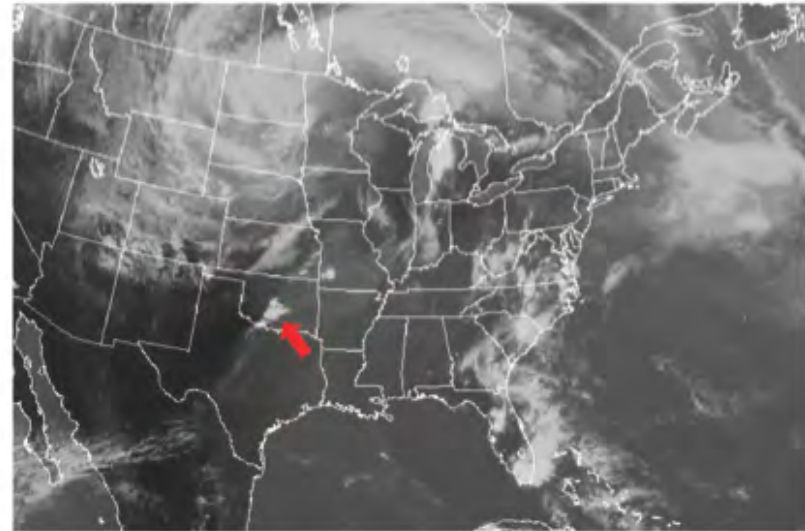
[Thomas et al., 2016]

# Development of Tornado Cell

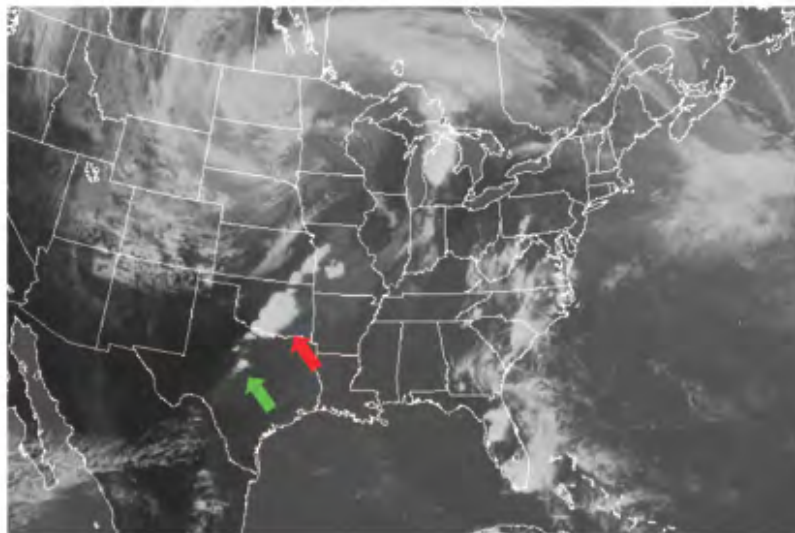
(a) 18:15(UT) 05/20 2013



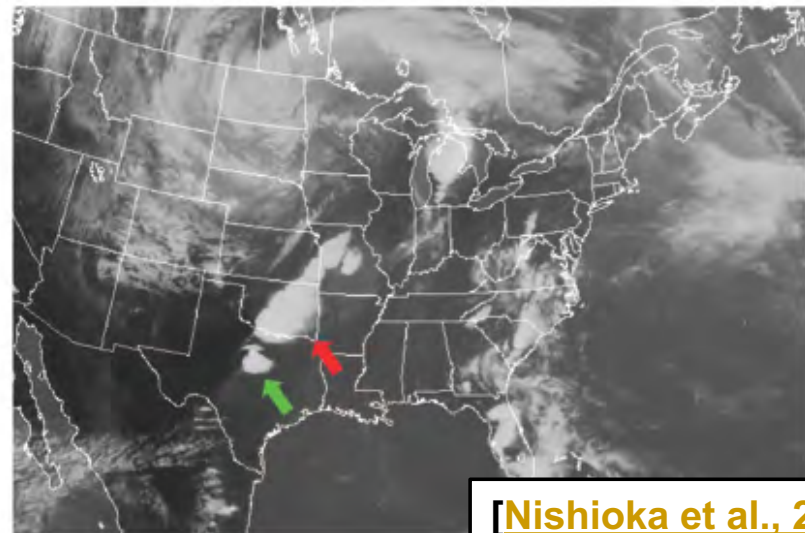
(b) 19:15(UT) 05/20 2013



(c) 20:15(UT) 05/20 2013

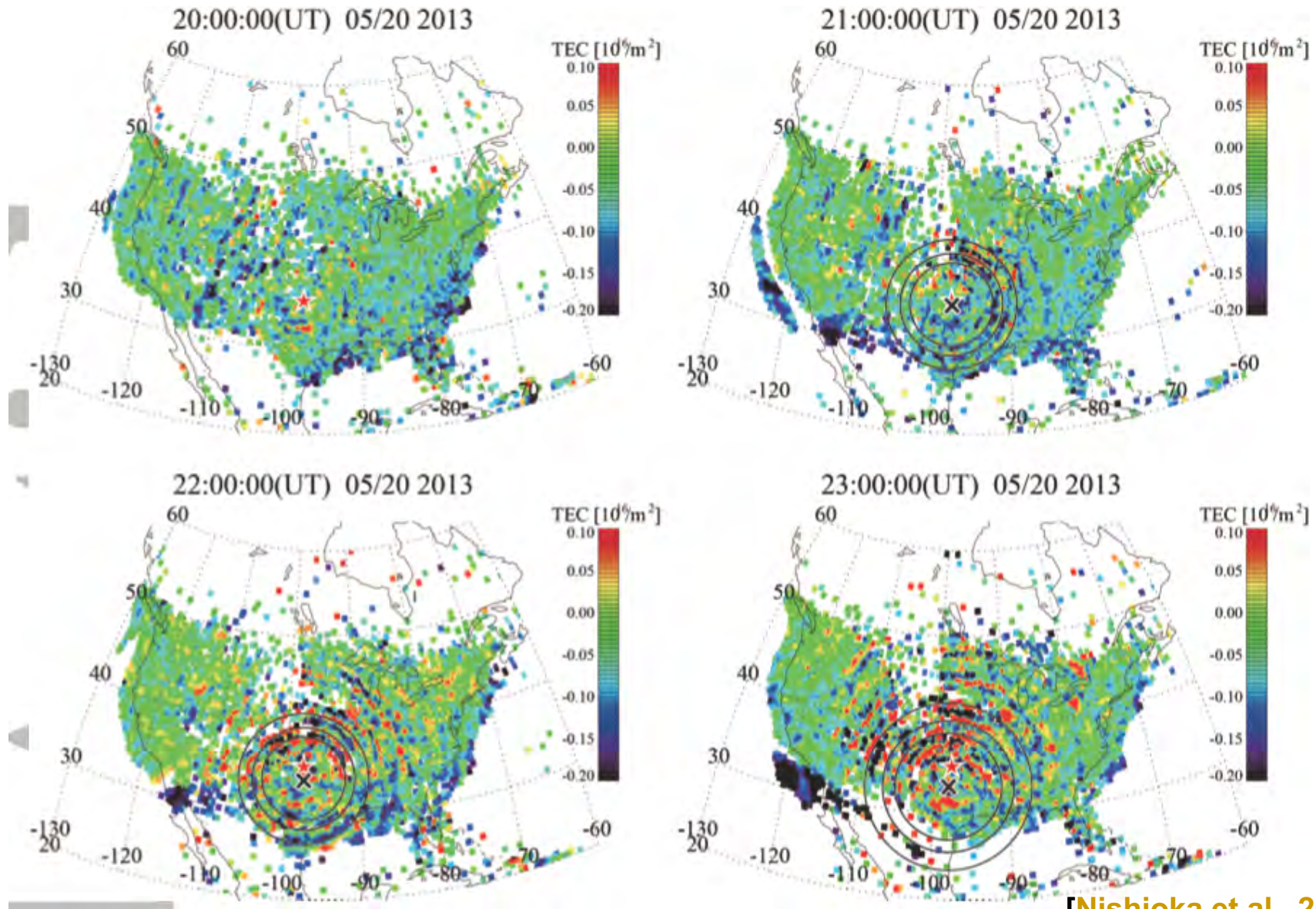


(d) 21:15(UT) 05/20 2013



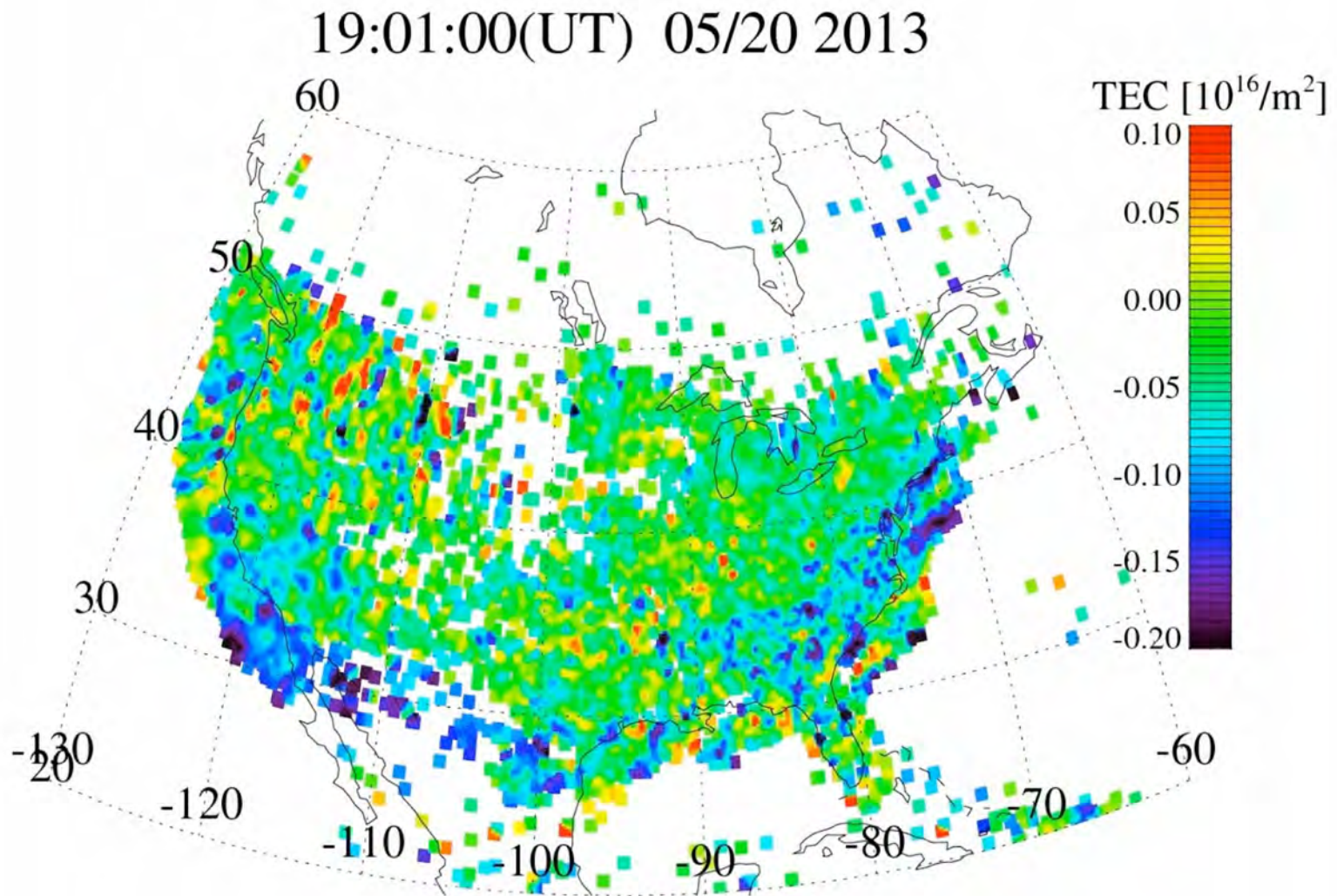
[Nishioka et al., 2013]

# MSTID Resulting from Tornado



[Nishioka et al., 2013]

# MSTID Resulting from Tornado



[Nishioka et al., 2013]

# Ionospheric Scintillation

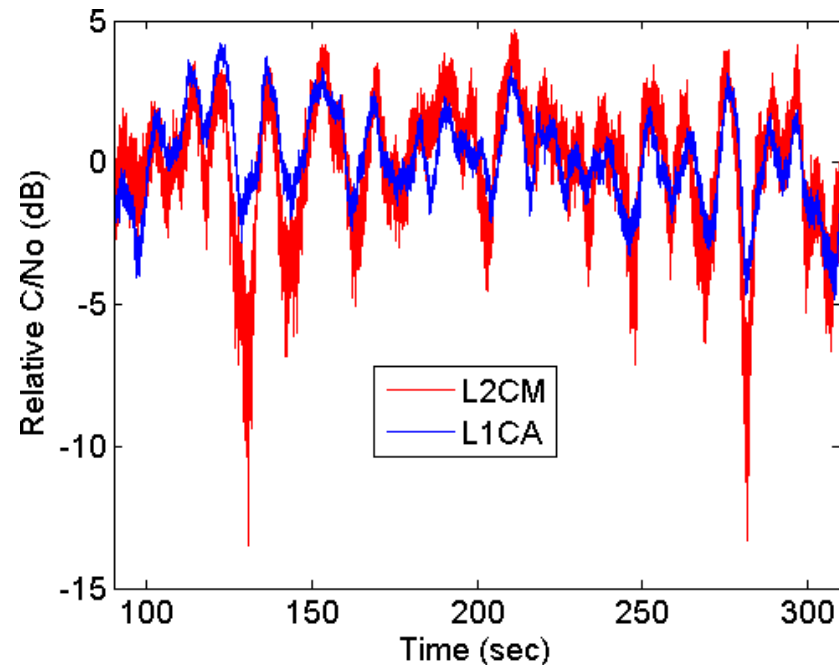
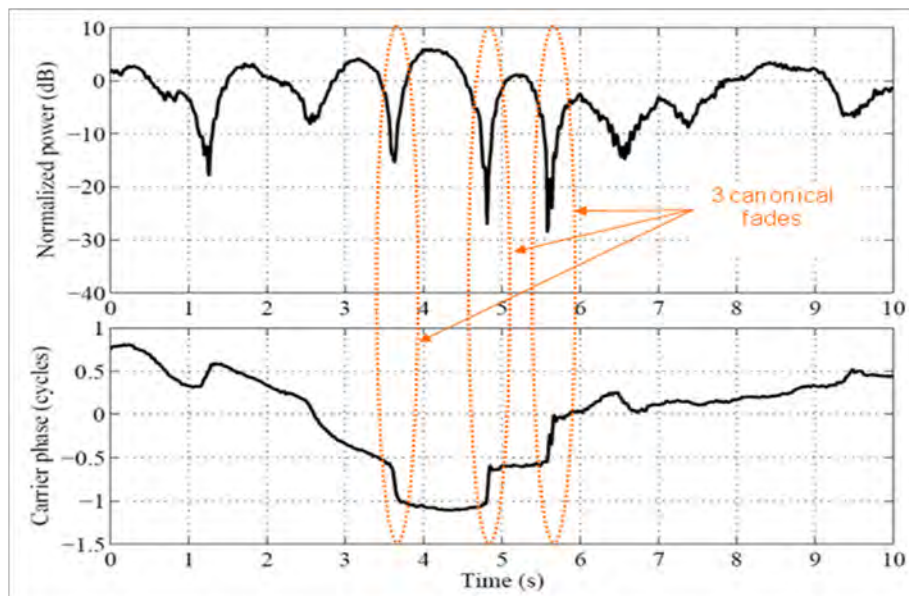
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- Caused by ionospheric turbulence (e.g. equatorial spread F) creating density structures with a length scale comparable with the signal wavelength
- This causes the waves to diffract and scatter causing interference
- At receiver both wave amplitude and phase vary on short time scale leading to signal loss

# Ionospheric Scintillation

Ionospheric scintillation affects both signal amplitude and phase.

- Amplitude and phase scintillation are not independent
- L1 and L2 frequency fades are not independent
- L2 frequency fades are larger





# Incoherent Scatter Radar (ISR)

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# Incoherent Scatter Radars



# Arecibo ISR

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- Located in Puerto Rico
- Operating since 1963
- Initiated by William E. Gordon
  - Pioneer of ISR
  - Born Patterson, NJ
  - Undergrad Montclair State
- Largest radar dish (305 m)
- 440 MHz, 1-2 MW



# Jicamarca ISR

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- Located in Peru
- Operating since 1961
- Phased array of 18,432 dipole elements covering 85,000 m<sup>2</sup>
- Located in the desert, very good signal-to-noise measurements
- 49.9 MHz, 3\*1.5 MW



# Millstone Hill ISR

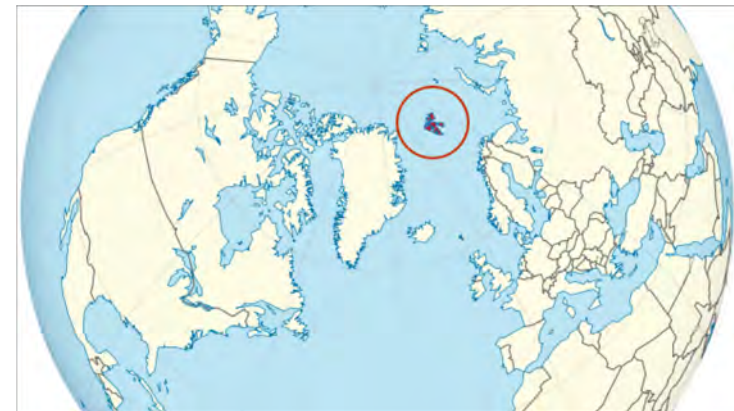
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- Located near Westford (outside Boston, MA)
- Operating since 1974
- One vertical 67 m dish, one fully-steerable 46 m dish
- 440 MHz, 2.5 MW



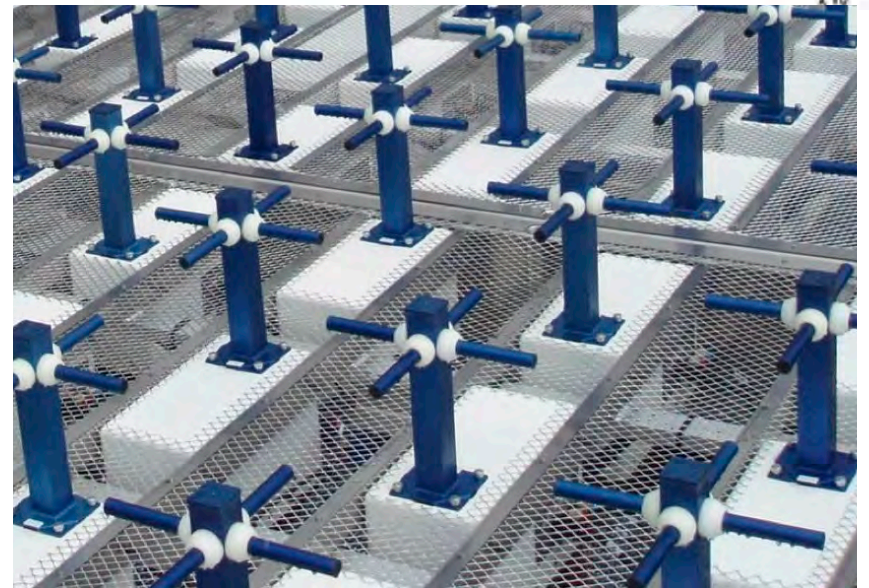
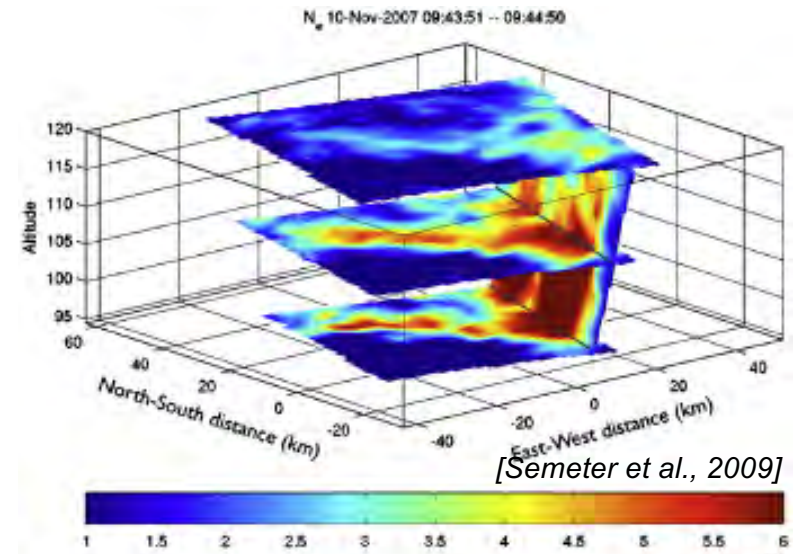
# EISCAT Svalbard Radar (ESR)

- Located here in Longyearbyen, Svalbard
- One fully steerable 32 m antenna (since 1996), one fixed 42 m antenna (since 2000)
- 500 MHz, 1 MW



# Poker Flat ISR (PHISR)

- AMISR Phased Array (30×30m)
- Poker Flat, Alaska
- 450 MHz, 1.3 MW
- Operational since 2007

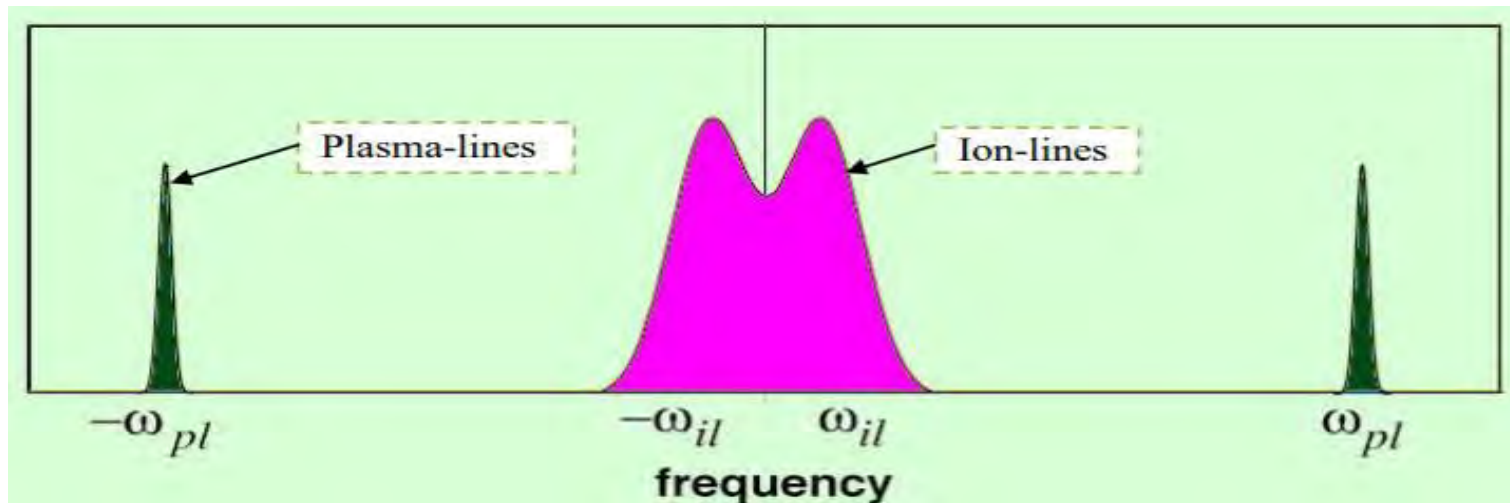


# ISR Power Spectrum

**ISRs detect scatter from single electrons by Thompson Scattering (scattering of EM radiation by a free particle)**

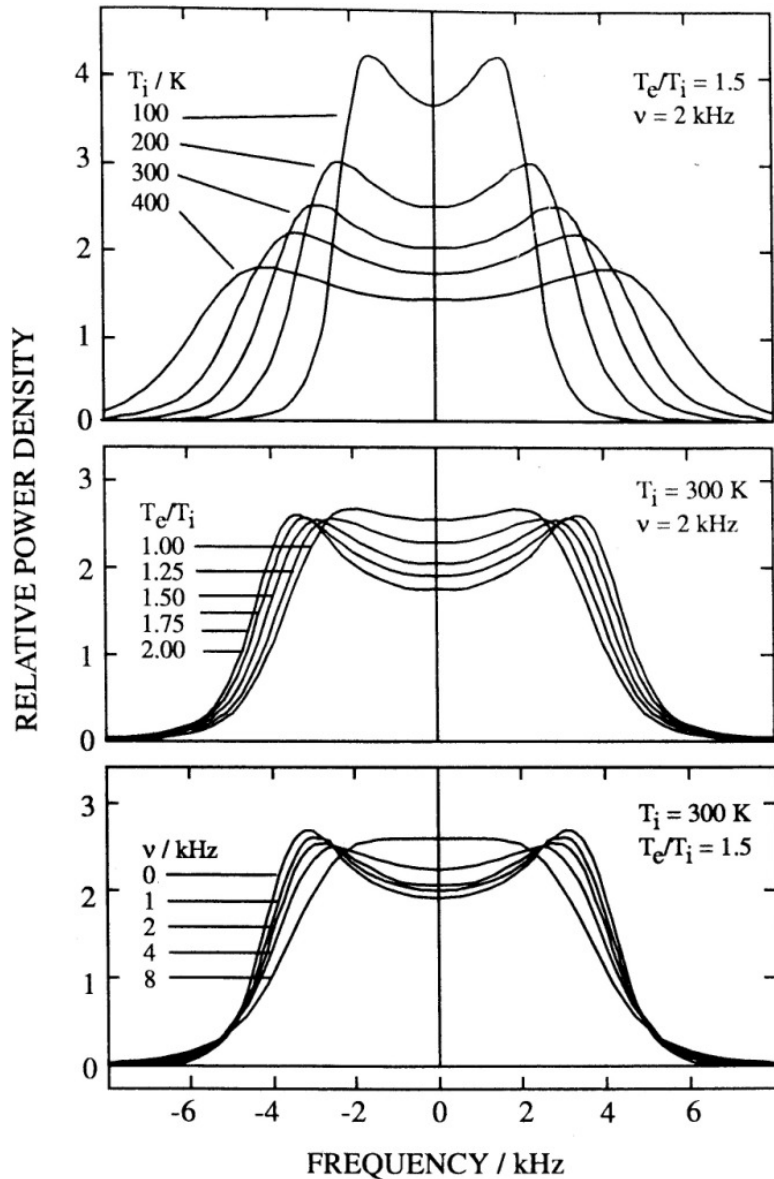
- The radar transmits a radio wave
- This hits the ionospheric free electrons, which are in random thermal motion
- The radio wave causes the electrons to oscillate
- They then emit their own radio waves in all directions
- Only a small fraction of the energy returns back to the radar

$$P_t = 1 \text{ MW}, P_r = 10^{-18} \text{ W}$$





# Ion acoustic power spectrum



- Fit data to model to extract 6 key ionospheric parameters:
  - Electron number density ( $n_e$ )
  - Electron temperature,  $T_e$
  - Ion temperature,  $T_i$
  - Ion composition,
  - Ion velocity,  $\nu$
  - Ion-neutral collision frequency,  $\nu_{in}$
- And estimates of the errors in these parameters

# Data: Auroral Substorm (Nightside)



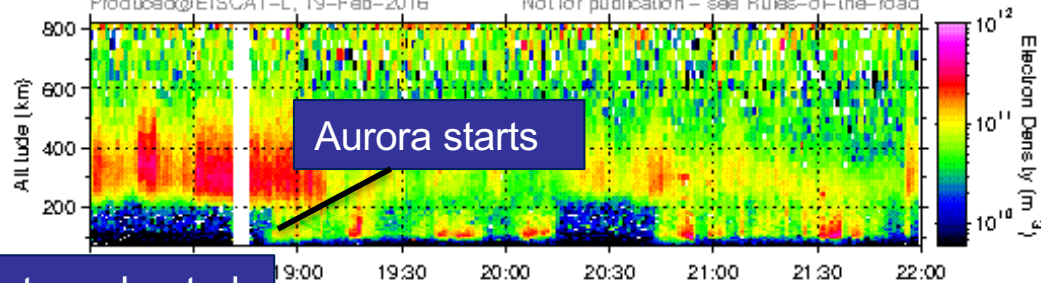
EISCAT Scientific Association

EISCAT SVALBARD RADAR

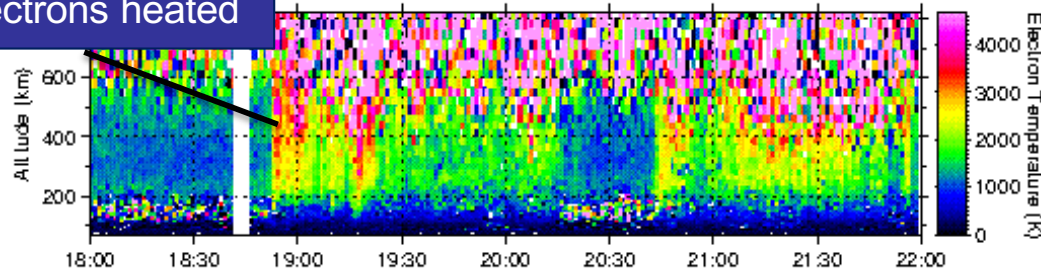
NO, 42mc, taro, 19 February 2016

Produced@EISCAT-L, 19-Feb-2016

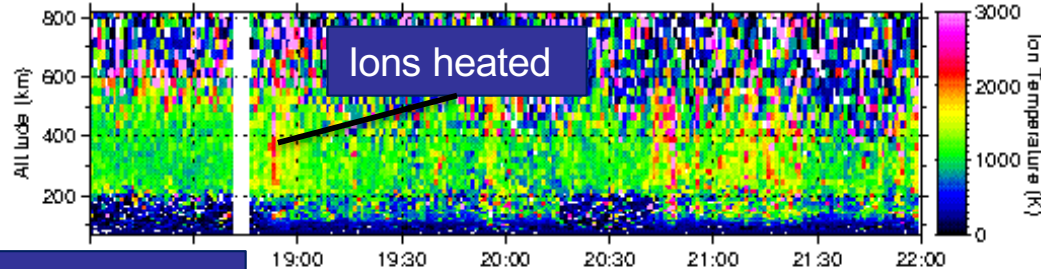
Not for publication - see Rules-of-the-road



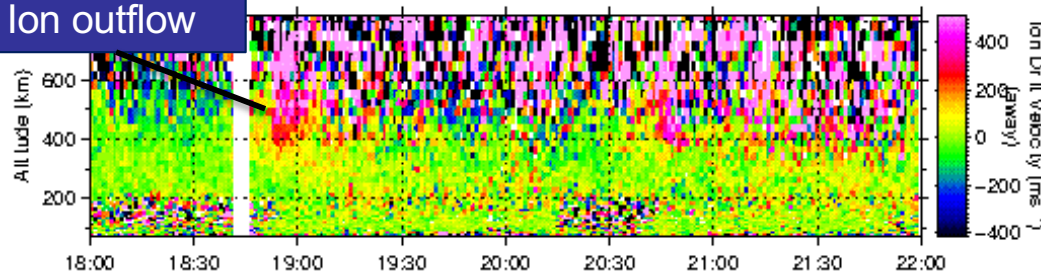
Electrons heated



Ions heated



Ion outflow



- We can see signatures of aurora. The incoming energetic auroral particles collide with the atmospheric particles
- There is more ionization and heating due to these collisions
- Ions also flow outwards into space

frissell@njit.edu

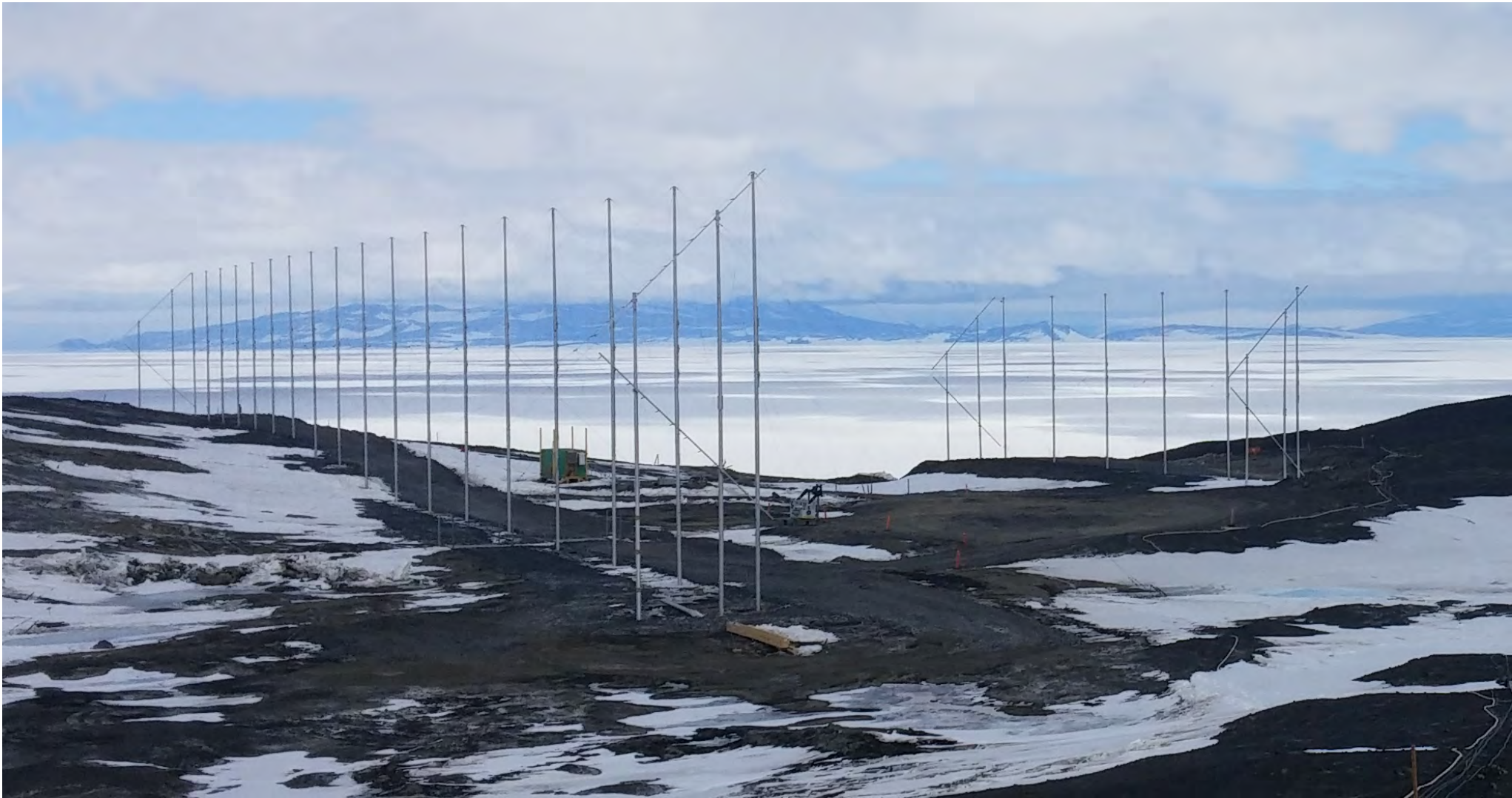
# SuperDARN

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COHERENT SCATTER RADAR

# Super Dual Auroral Radar Network

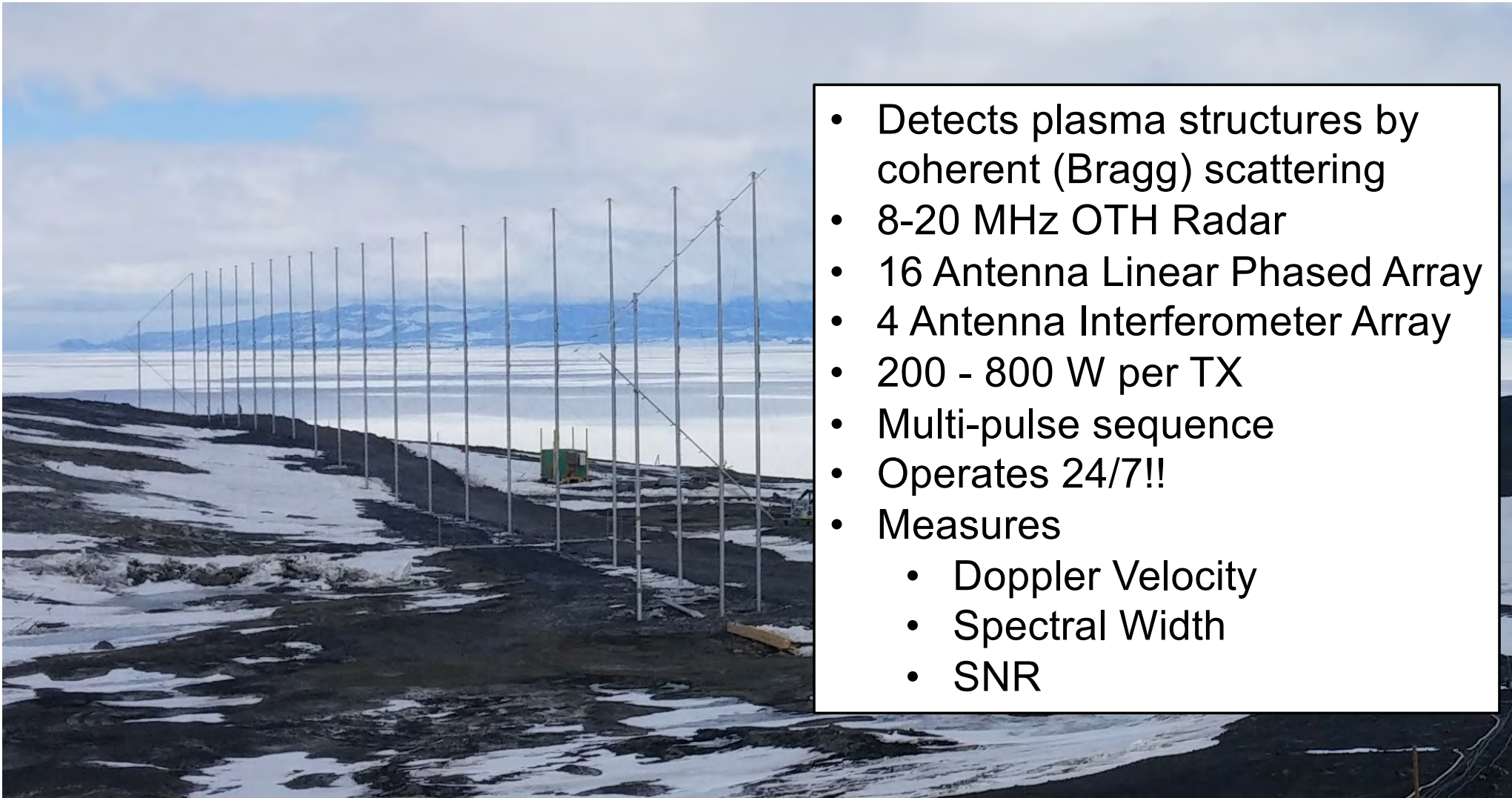
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SuperDARN Radar, McMurdo Station Antarctica

Photo N. Frissell, 2014

# Super Dual Auroral Radar Network

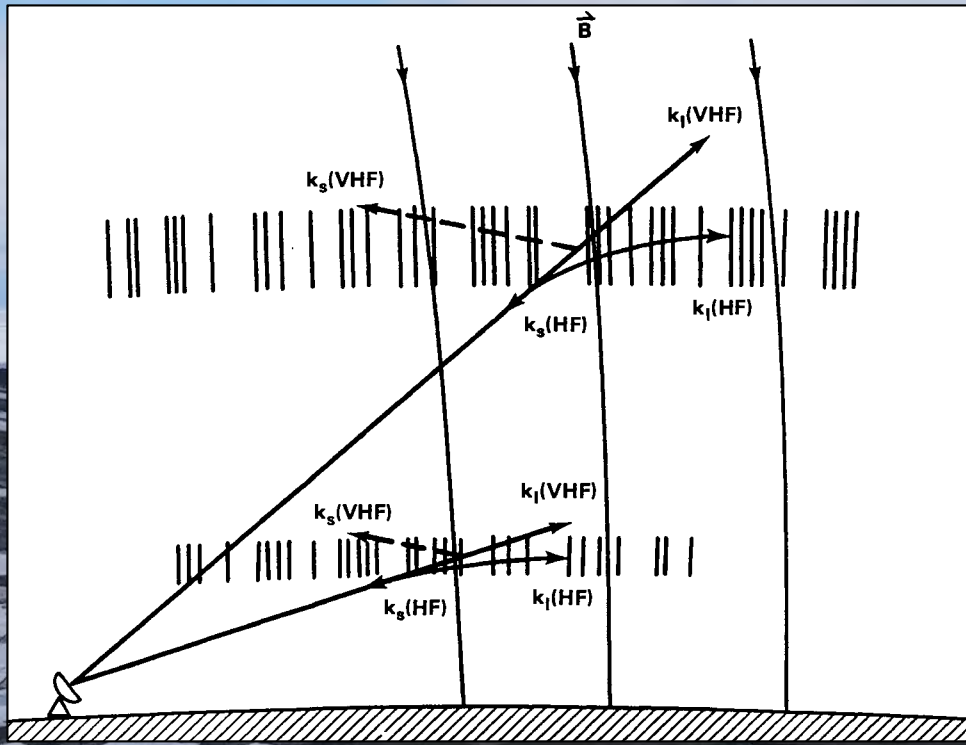


- Detects plasma structures by coherent (Bragg) scattering
- 8-20 MHz OTH Radar
- 16 Antenna Linear Phased Array
- 4 Antenna Interferometer Array
- 200 - 800 W per TX
- Multi-pulse sequence
- Operates 24/7!!
- Measures
  - Doppler Velocity
  - Spectral Width
  - SNR

SuperDARN Radar, McMurdo Station Antarctica

Photo N. Frissell, 2014

# Super Dual Auroral Radar Network



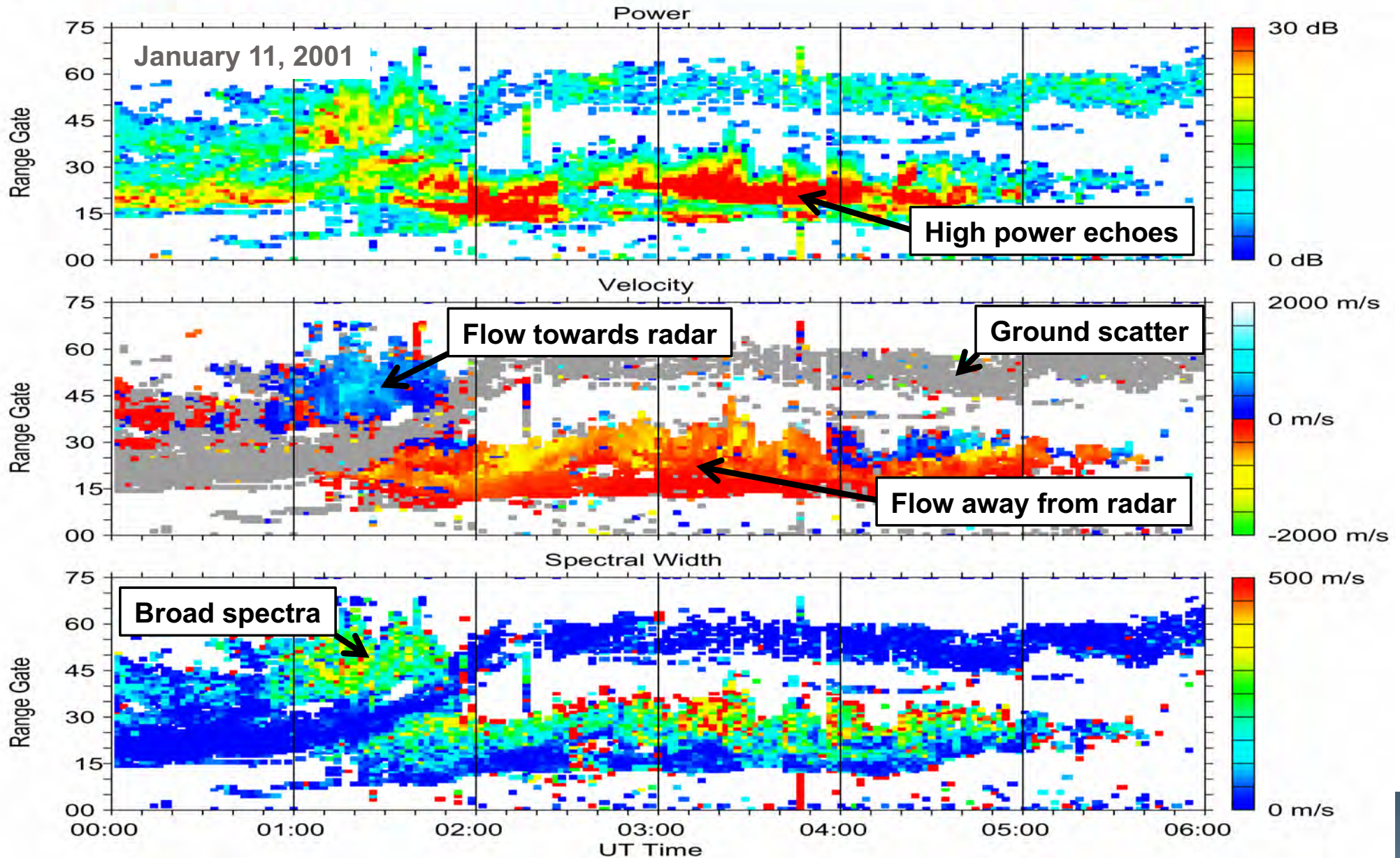
[Greenwald et al., 1995]

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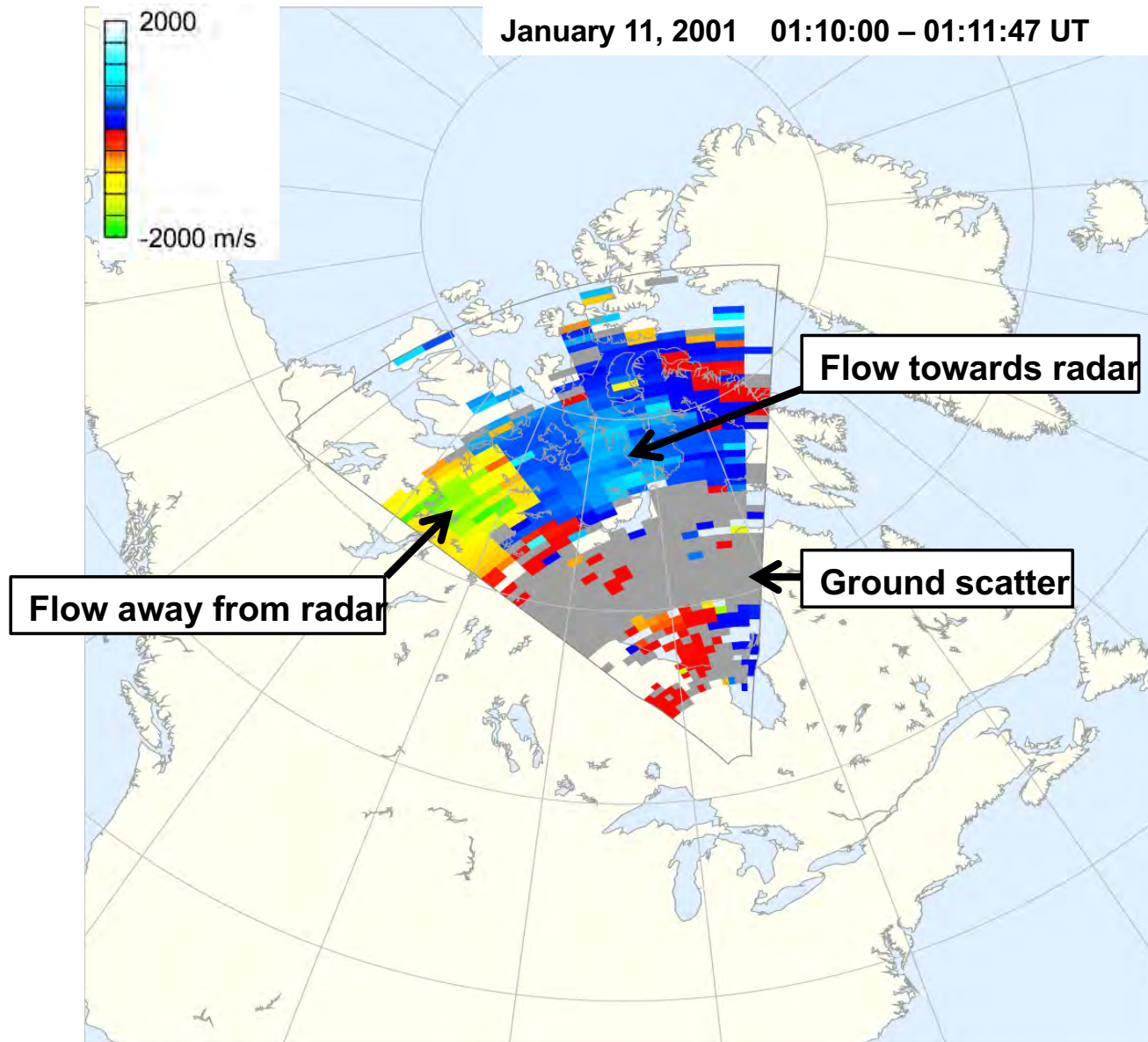
SuperDARN Radar, McMurdo Station Antarctica

Photo N. Frissell, 2014

# Range-Time Plot – Beam 4 Kapuskasing



# Doppler Velocity Map – Kapuskasing

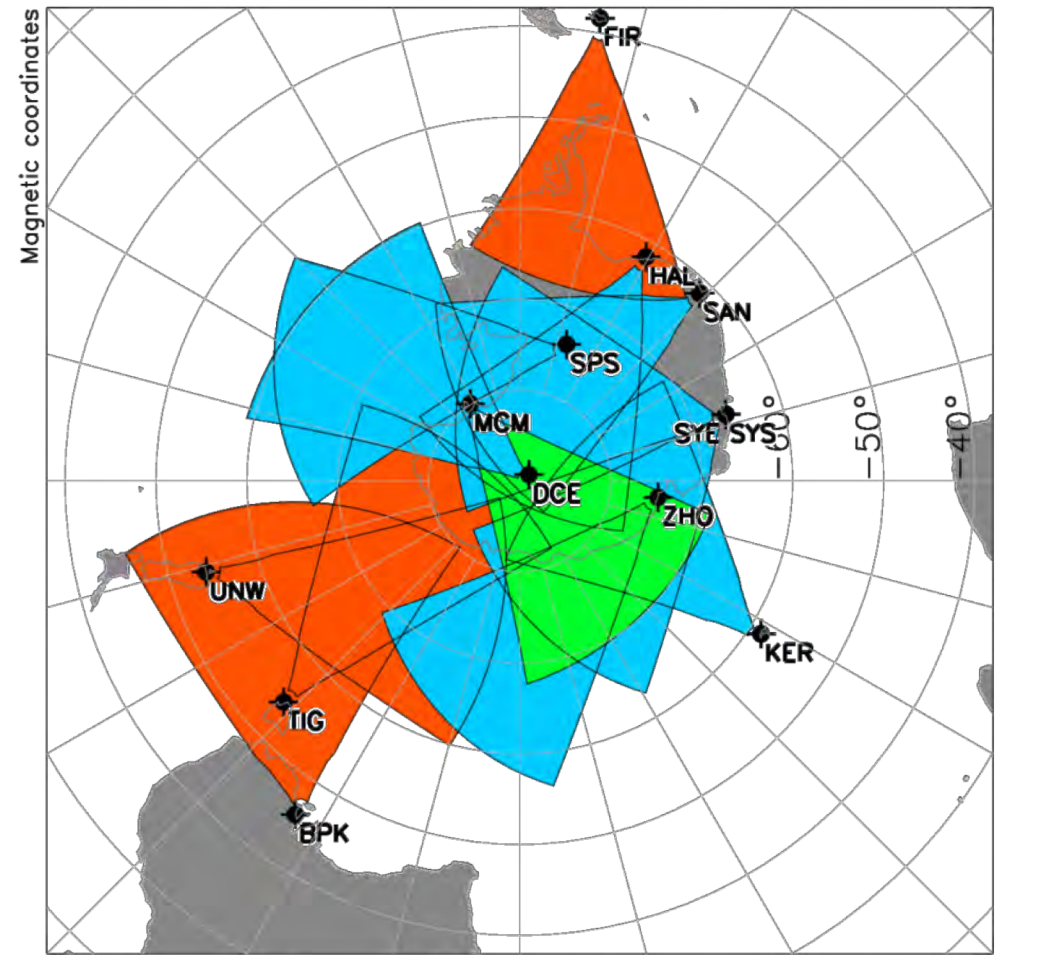
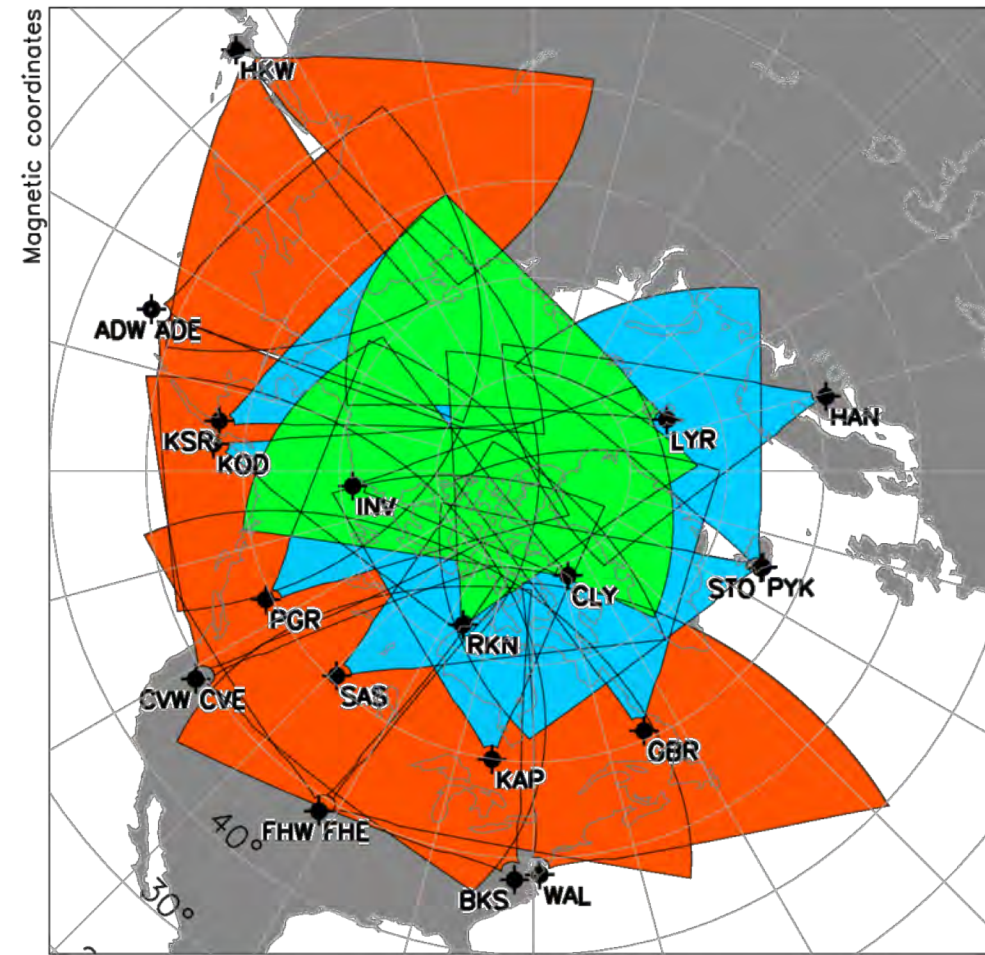




# Super Dual Auroral Radar Network

## Northern Hemisphere

## Southern Hemisphere



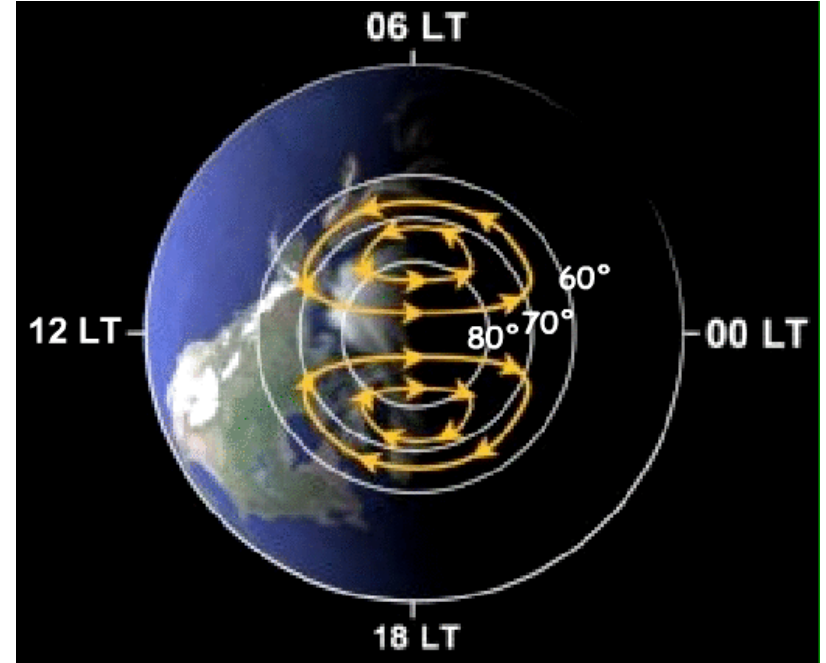
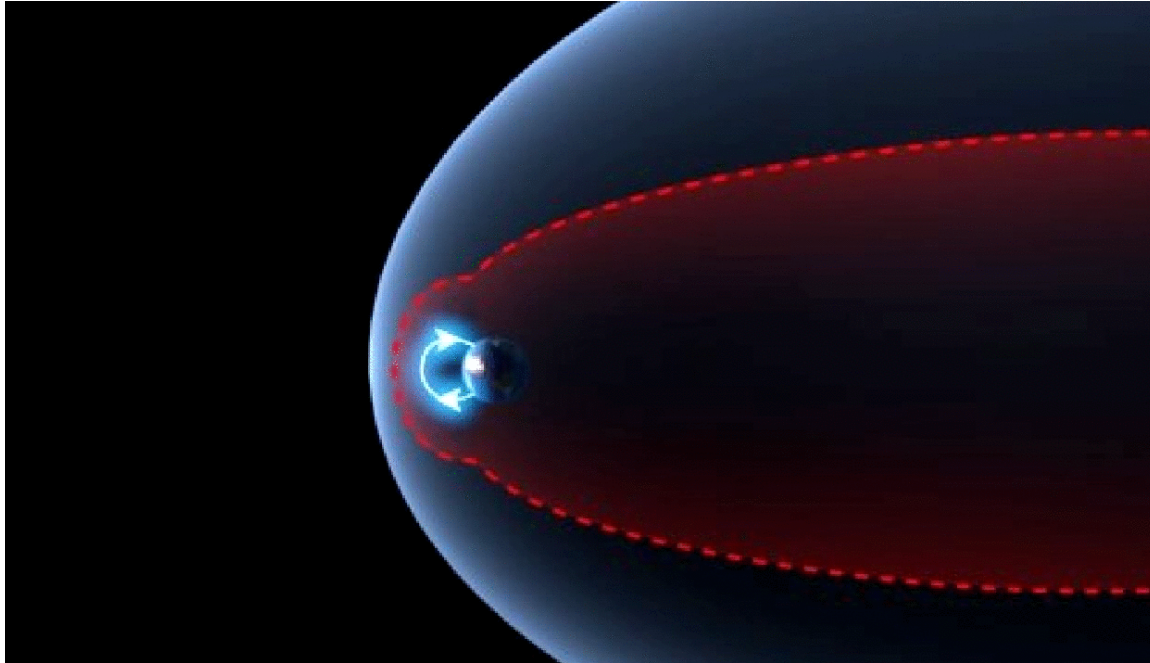
High-latitude

Mid-latitude

Polar cap

[\[http://vt.superdarn.org, 15 Sept 2018\]](http://vt.superdarn.org)

# Magnetospheric Convection



©The COMET Program / UCAR

HamSci  
<http://hamsci.org>

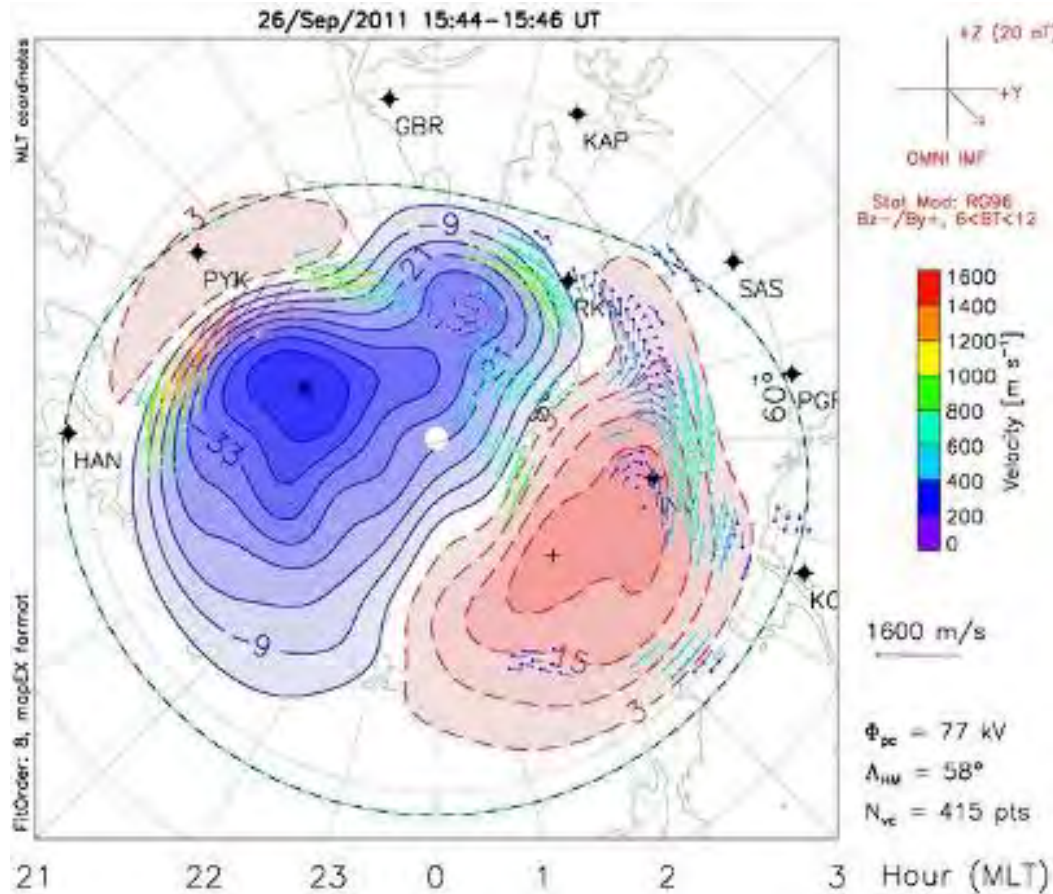
NJIT

frissell@njit.edu

# Super Dual Auroral Radar Network

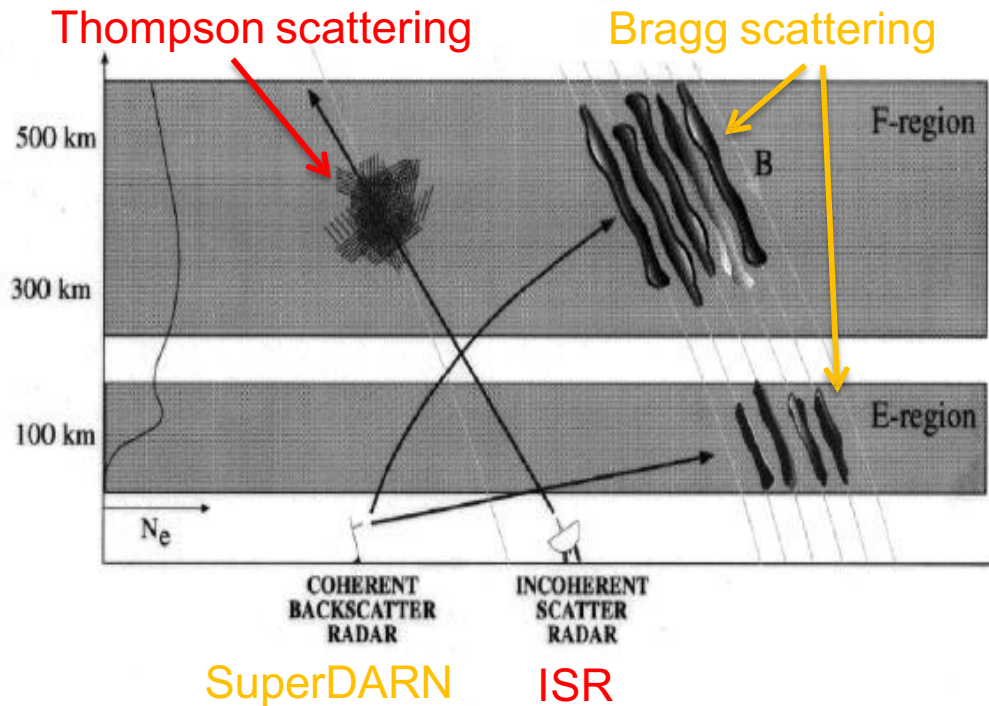
## SuperDARN

### Global Ionospheric Convection Maps



- Data is taken from all the radars and fitted to a model
- From this we can build a map of how the plasma is moving over large areas
- Helps us to get a global picture of plasma circulation

# EISCAT vs SuperDARN

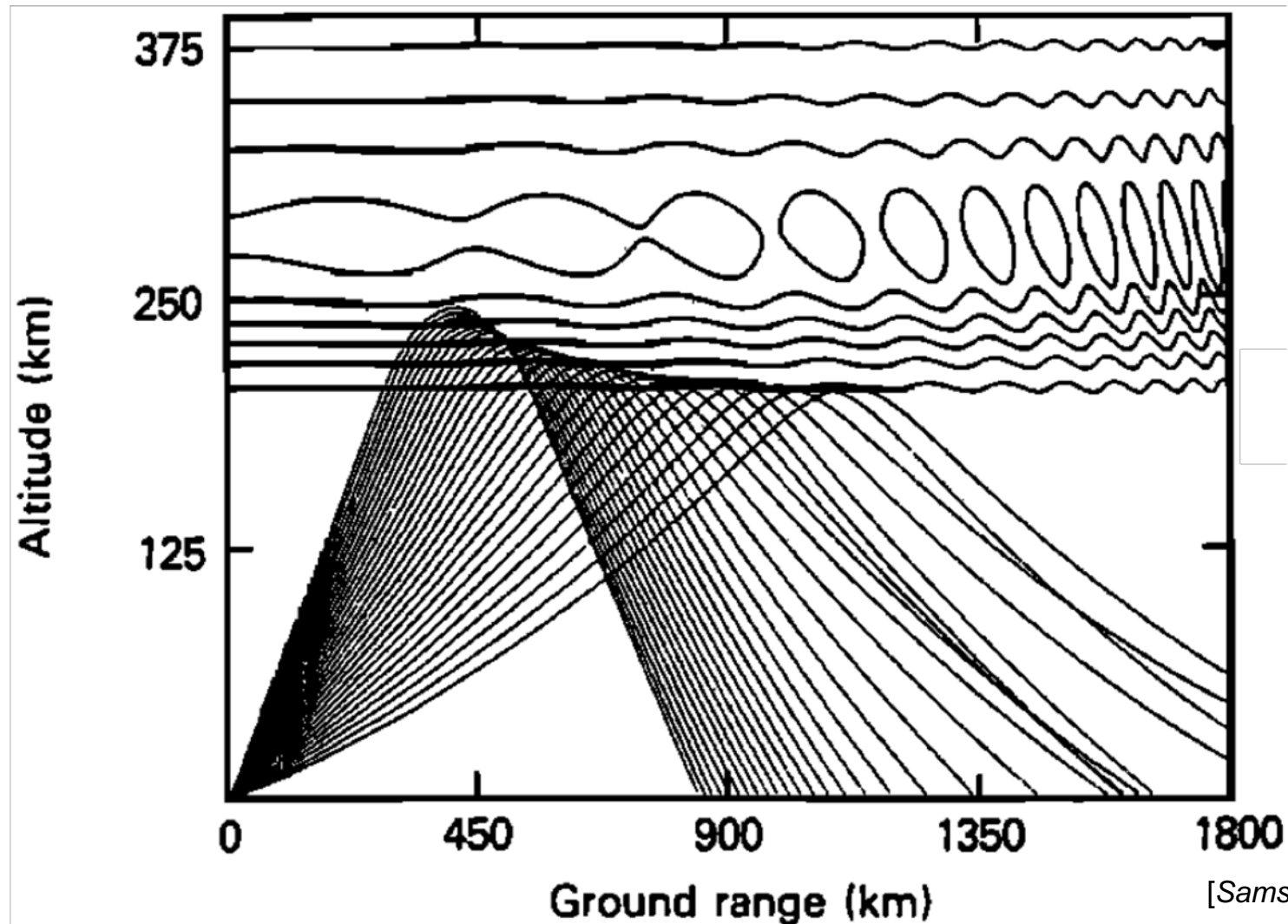


| Radar            | ISR                   | SuperDARN           |
|------------------|-----------------------|---------------------|
| Scatter type     | Incoherent (Thompson) | Coherent (Bragg)    |
| Frequency        | Fixed (500 MHz)       | Variable (9-20 MHz) |
| Range resolution | ~100m-10km            | 15-45 km            |
| Field of view    | Narrow                | Wide                |

- ISRs see smaller structures in any direction using Thompson scattering
- CSRs see bigger structures aligned with the magnetic field using Bragg scattering

# Medium Scale Traveling Ionospheric Disturbances

Now we are interested in the ground scatter...

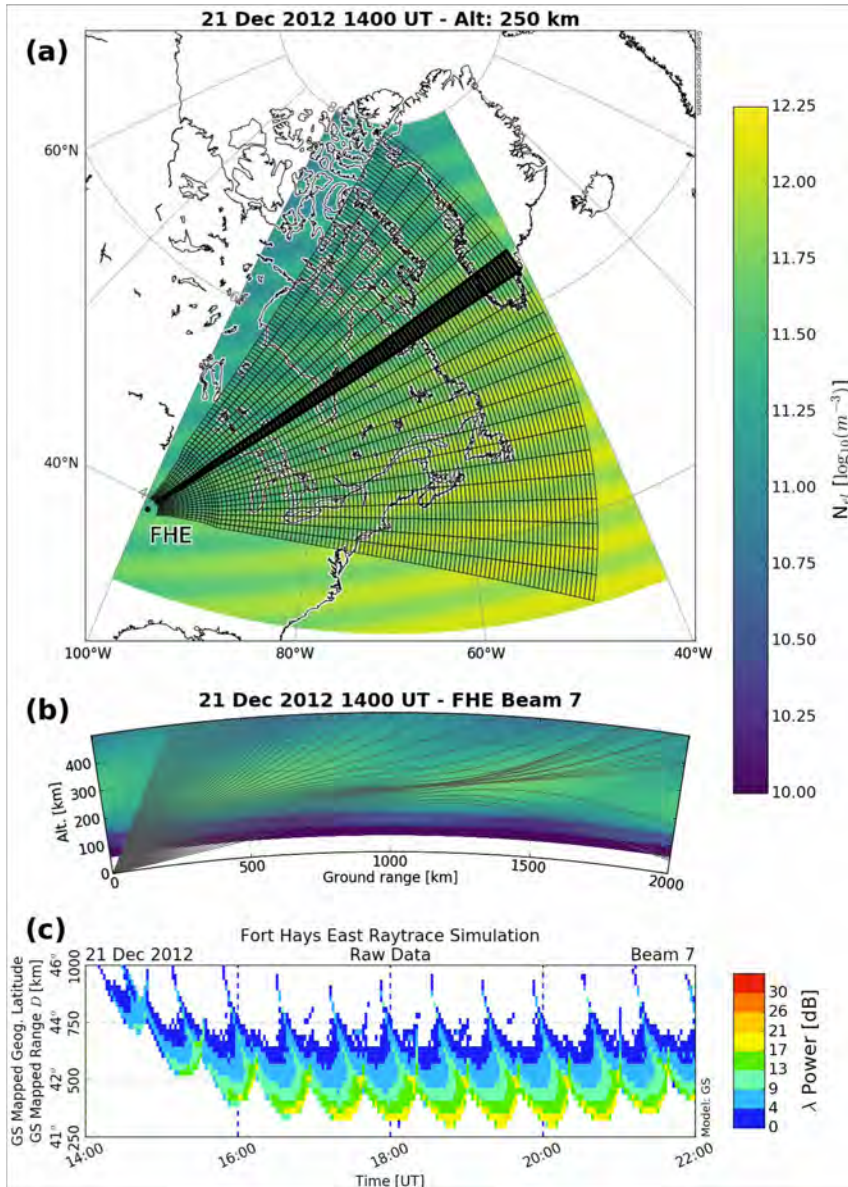


# Medium Scale Traveling Ionospheric Disturbances

Ray trace simulation illustrating how SuperDARN HF radars observe MSTIDs.

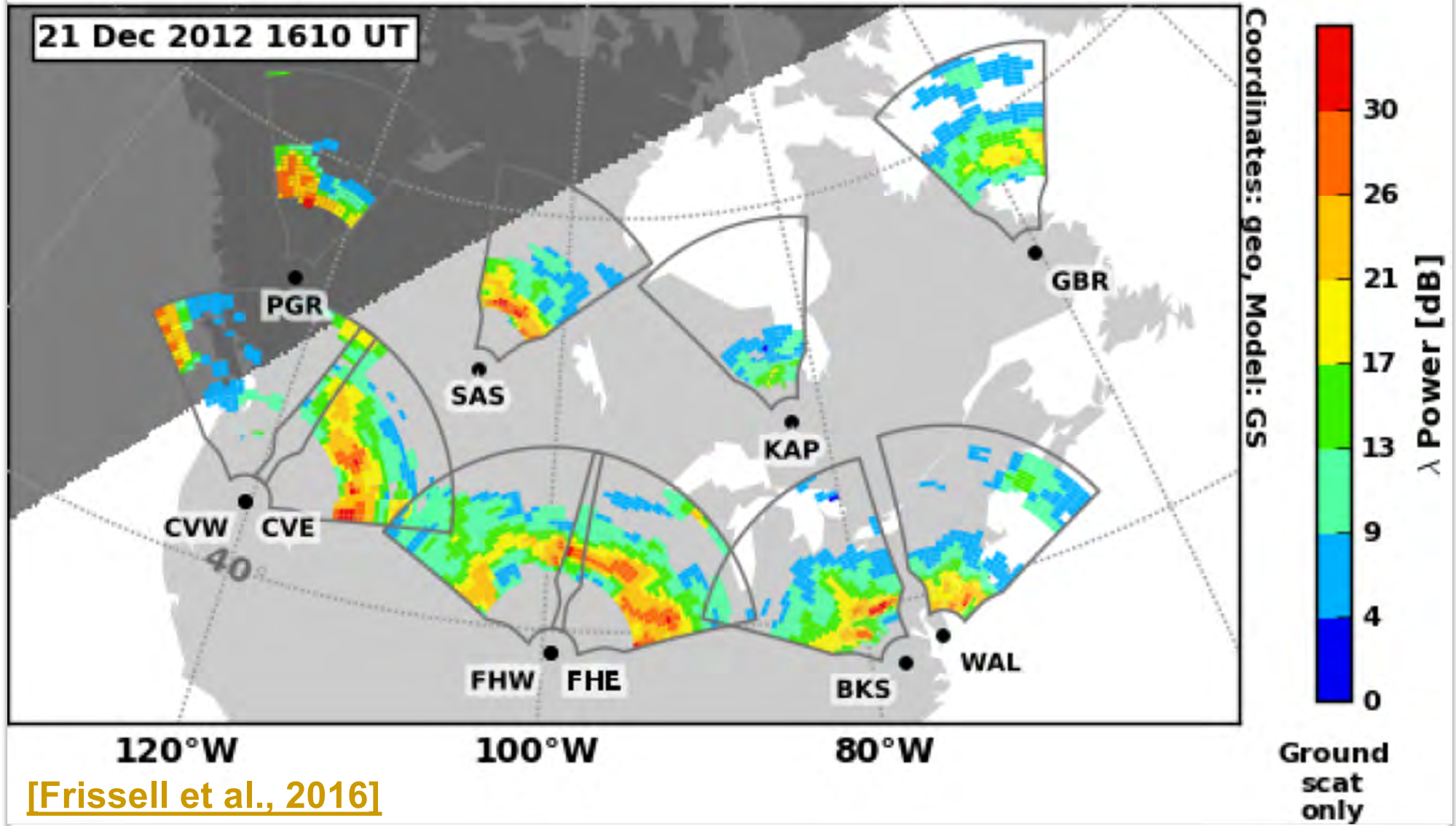
- (a) Fort Hays East (FHE) radar field of view superimposed on a 250 km altitude cut of a perturbed IRI. FHE Beam 7 is outlined in bold.
- (b) Vertical profile of 14.5 MHz ray trace along FHE Beam 7. Background colors represent perturbed IRI electron densities. The areas where rays reach the ground are potential sources of backscatter.
- (c) Simulated FHE Beam 7 radar data, color coded by radar backscatter power strength. Periodic, slanted traces with negative slopes are the signatures of MSTIDs moving toward the radar.

[Frissell et al., 2016]



# SuperDARN MSTID Study

## SuperDARN Ground Scatter Data



[Frissell et al., 2016]

# MSTIDs Caused by Aurora?



Svalbard, 2010, N. Frissell

HamSci  
<http://hamsci.org>

NJIT

[frissell@njit.edu](mailto:frissell@njit.edu)



# MSTIDs Caused by Aurora?

---

- Except for point sources, it is very difficult to track any single MSTID over its entire lifetime.
- Observational papers generally report
  - Equatorward propagation from high latitudes
  - Lots of activity in fall and winter
  - High and midlatitude MSTIDs are similar
- 1970s Theory Linked MSTIDs to Auroral AGWs
  - Lorenz Forcing by Auroral Current Surges
  - Joule Heating by Auroral Particle Precipitation

[e.g., [Chimonas and Hines, 1970](#); [Francis, 1974](#)]

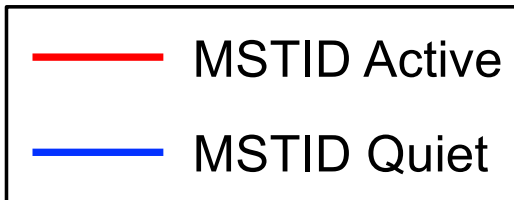
# MSTIDs Caused by Aurora?

---

- Many observational papers try to link MSTIDs to geomagnetic activity.
  - Theory
  - Equatorward propagation
  - Originates from Auroral Zone
- Correlation of MSTID observations with space weather indices is marginal.
- If not the aurora, what else could it be?

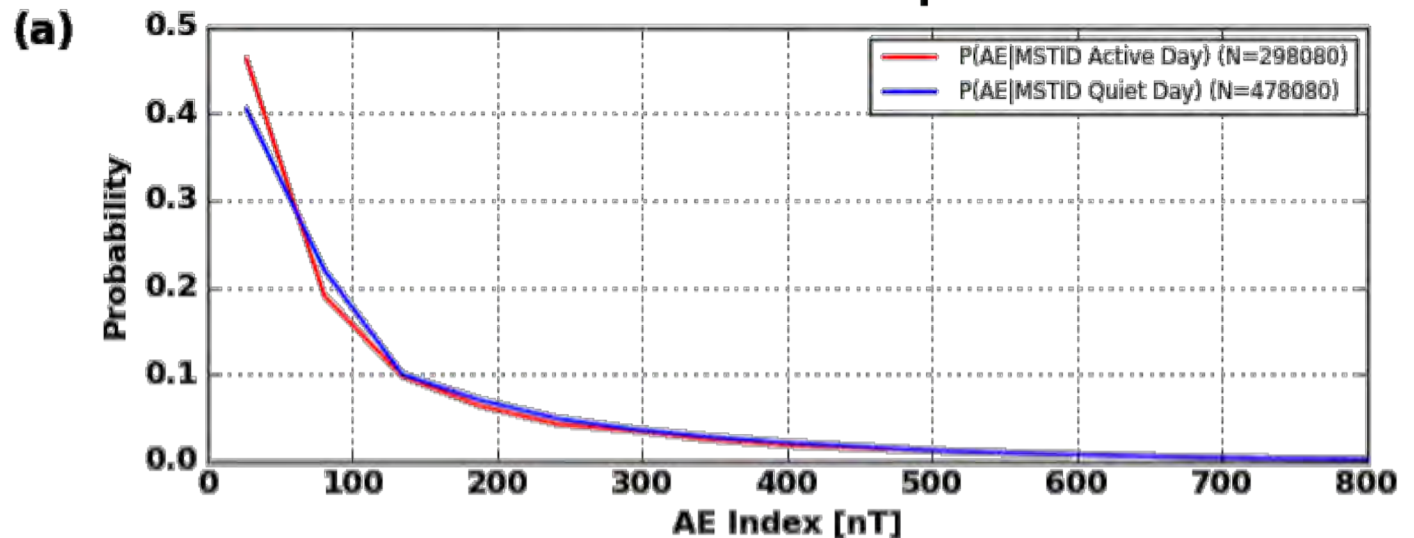
[*Samson et al.*, 1989, 1990; *Bristow et al.*, 1994, 1996; *Grocott et al.*, 2013; *Frissell et al.*, 2014]

# Is it the Aurora?

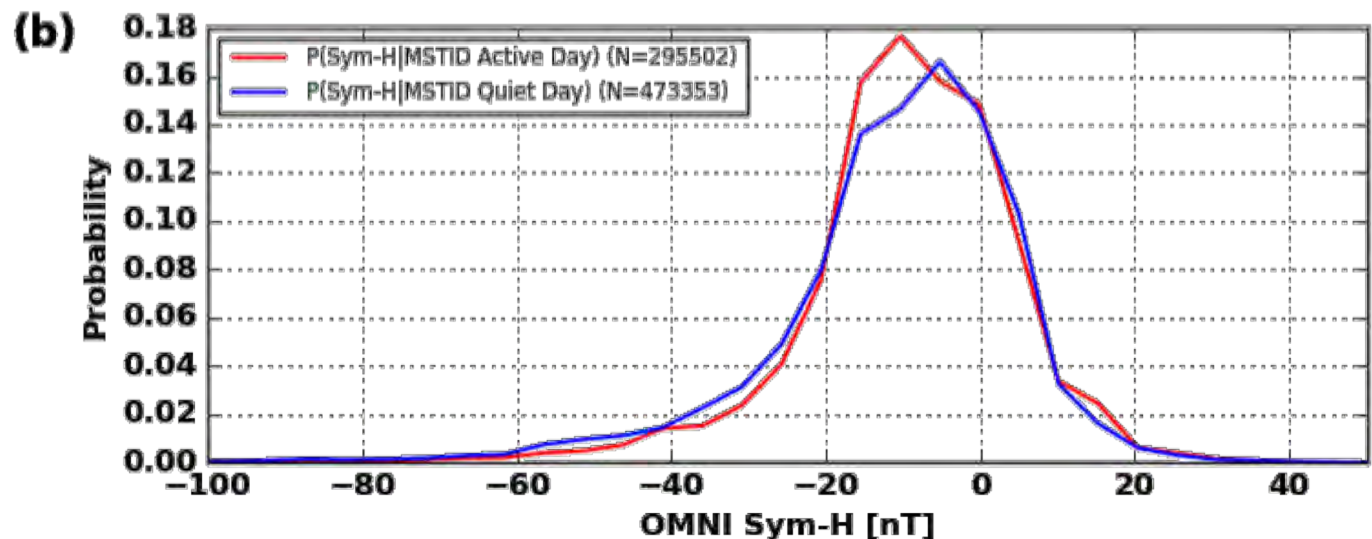


**AE**

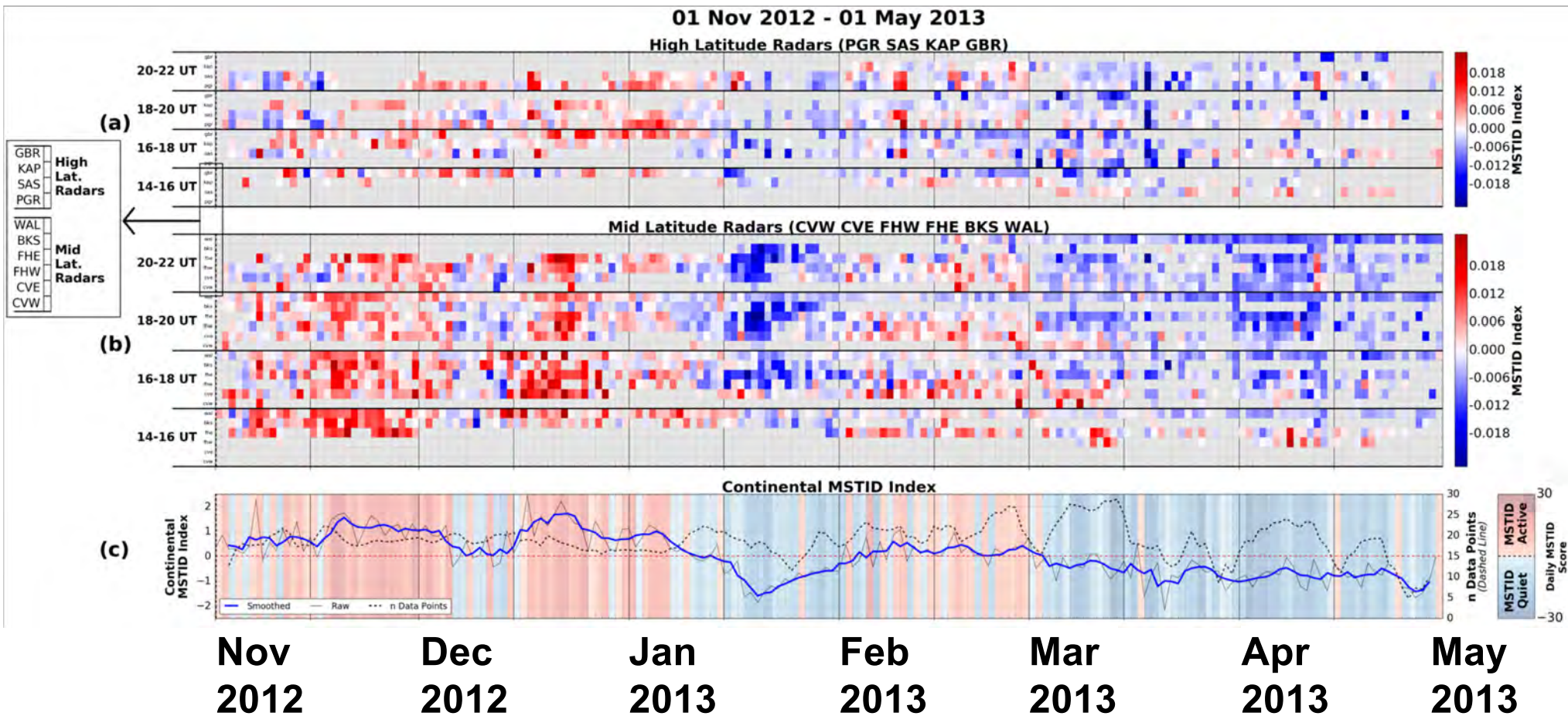
SuperDARN MSTID Active/Quiet Day Probabilities  
01 Nov 2012 - 30 Apr 2015



**SYM-H**



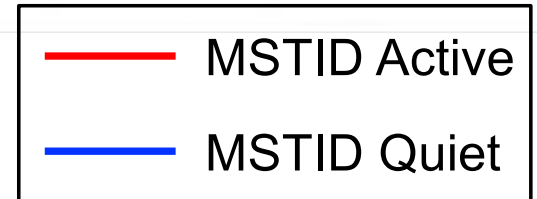
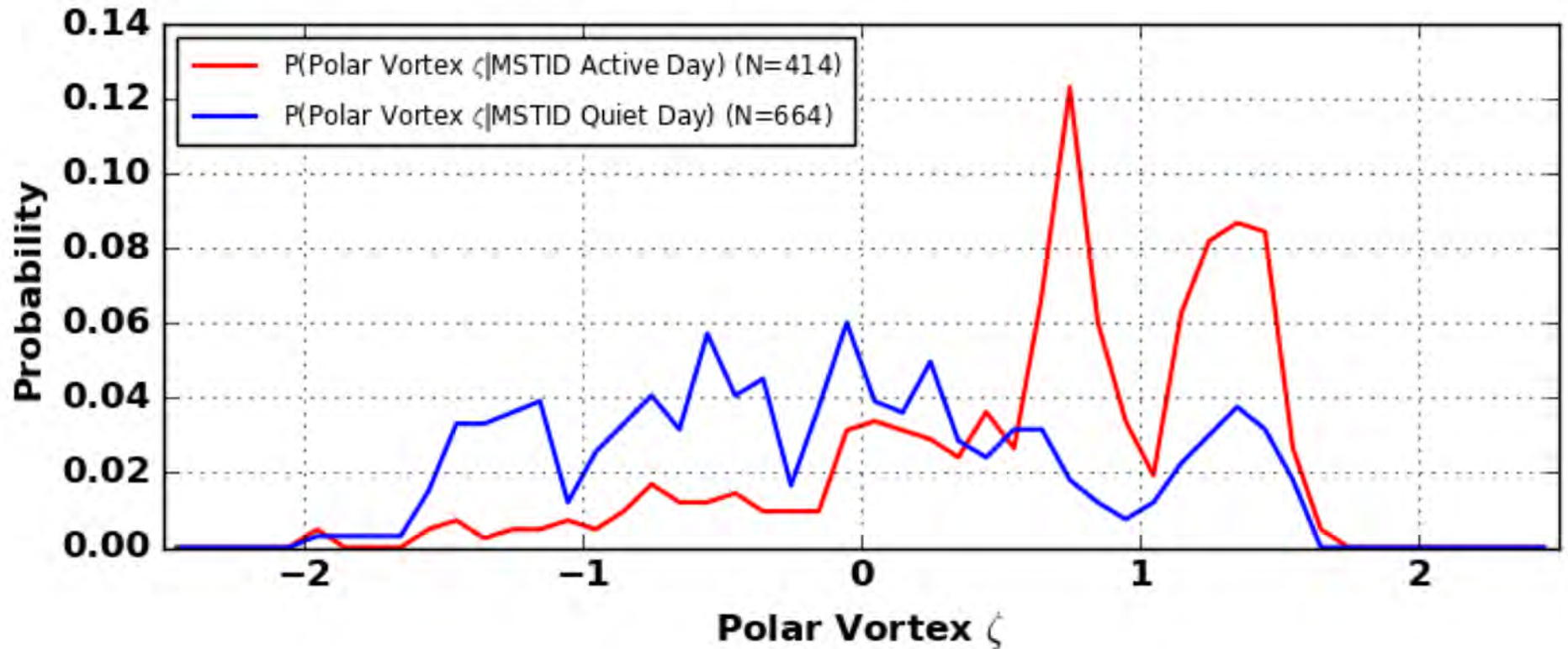
# MSTIDs Nov 2012 – May 2013



— MSTID Active  
— MSTID Quiet

[Frissell et al., 2016]

# Correlation with Polar Vortex!



# SuperDARN Achievements

---

- Hemispheric structure and dynamics of ionospheric convection
- Mesoscale signatures of magnetosphere-ionosphere coupling:
  - Convection vortices associated with field-aligned currents
  - Ionospheric flow bursts associated with transient magnetic reconnection or FTEs
- Inter-hemispheric conjugacy of ionospheric convection
- Convection associated with auroral substorms
- Ionospheric irregularities and high latitude plasma structures (patches)
- Electromagnetic waves: MHD, ULF, Magnetic Field Line Resonances
- Neutral atmosphere: Gravity waves, mesospheric winds, planetary waves
- More generally, SuperDARN convection patterns have been widely used to interpret localized features in other ground and space-based datasets

# Ionospheric Modification

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# Ionospheric Modification (Heating)

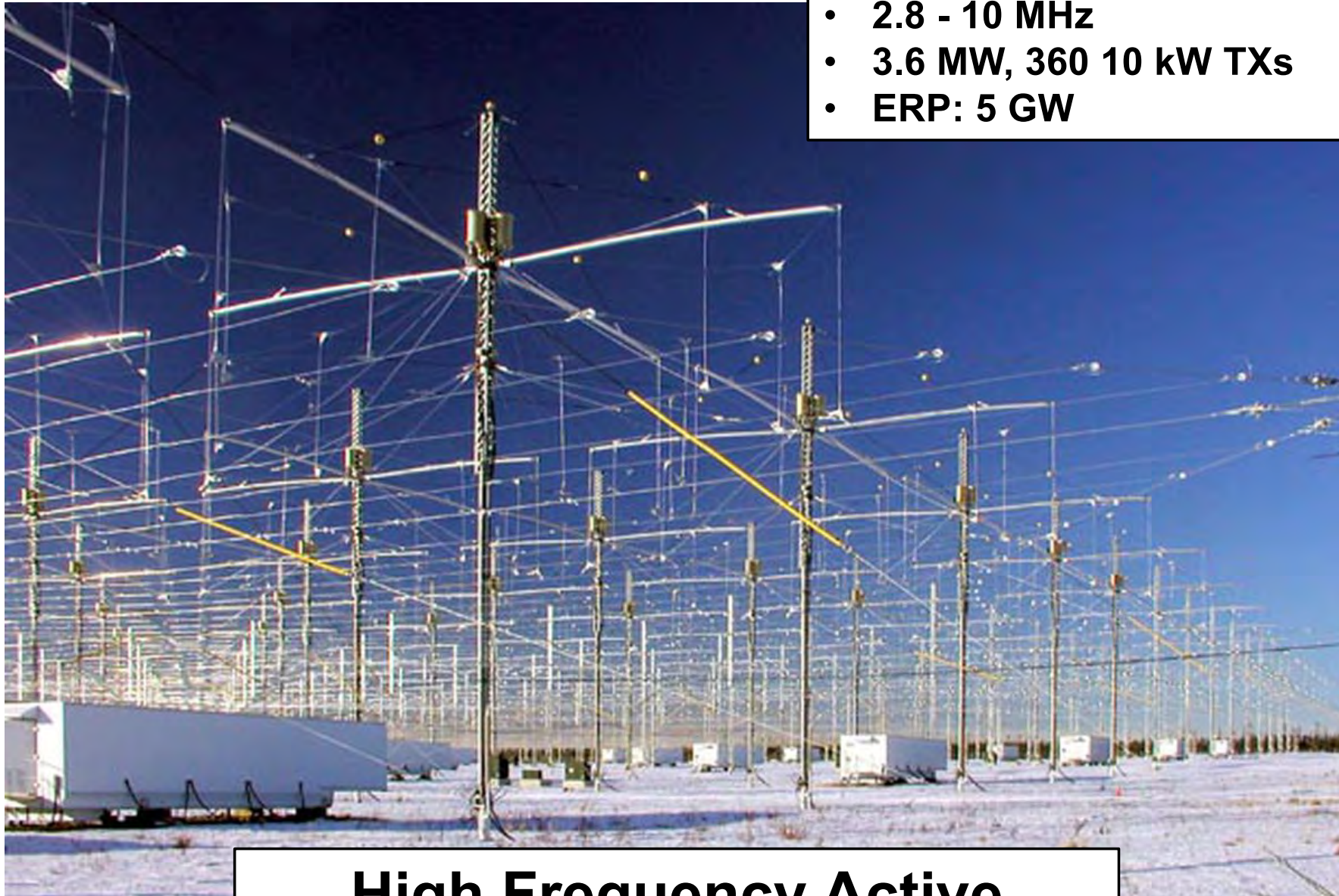
---

- HF ionospheric heaters can turn the ionosphere into a plasma-physics laboratory
- Electron acceleration processes
- Ionospheric structure irregularities at meter to sub-kilometer scales
- Electron thermal balance
- Resonant ion oscillations
- Airglow optical emissions (artificial aurora)
- Generation of ELF and ULF (Submarine communication)
- Enhanced plasma lines



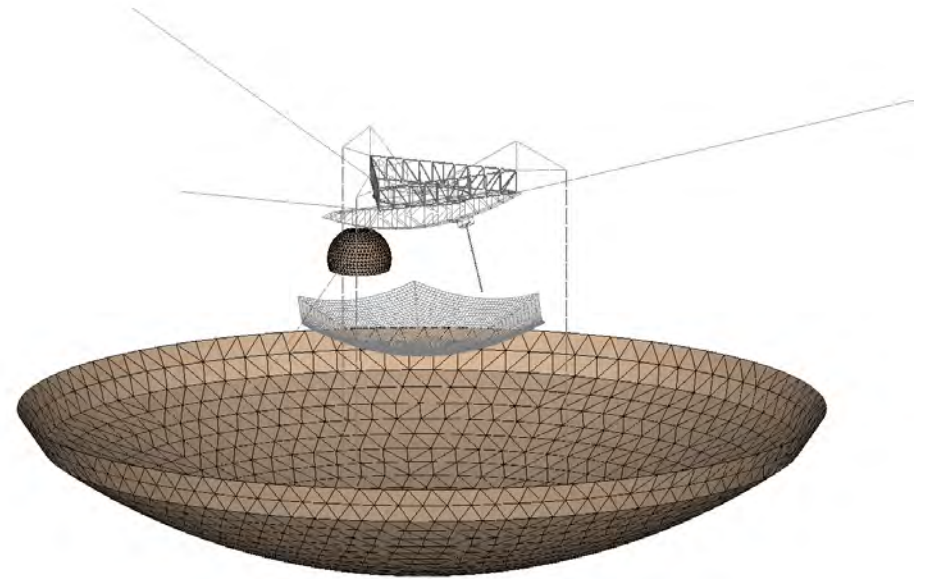
# HAARP

- Gakona, AK
- 180 crossed dipole (12 x 15)
- 2.8 - 10 MHz
- 3.6 MW, 360 10 kW TXs
- ERP: 5 GW



## High Frequency Active Auroral Research Program

# Arecibo



James K. Breakall, WA3FET

- ERP(5.1 MHz) = 99.6 MW (600kW TX power)
- ERP(8.175 MHz) = 212.9 MW (600kW TX power)

# Signals of Opportunity

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# Signals of Opportunity

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- Many ionospheric experiments require a transmitter
- Transmitters are often inconvenient
  - Licensing Issues
  - Spectrum Management Considerations
  - Power Limitations
  - Space Limitations
- So, just listen to someone else's transmitter...
  - WWV/CHU HF Standards Stations
  - CODAR HF Ocean Radars
  - Broadcast Radio Stations
  - VLF Transmitters

# HF Frequency Measurement Experiment

2017 Eclipse HF Frequency Measurement Experiment

Please bookmark this page and join the **HamSCI-Eclipse mailing list** for further announcements.

Rapid changes in ionospheric electron density caused by the motion of the shadow of an eclipse is known to cause Doppler shifts on HF ray paths propagating through the eclipse region. For example, see Figure 7 in **Boitman et al., 1999**. We request that all amateur radio stations capable of making high-quality HF frequency measurements participate in this experiment and publish their data to the **HamSCI community on the open-data sharing site zenodo.org**.

## Research Question

- How does the 2017 Total Solar Eclipse affect HF propagation paths?

## Objective

- Measure HF path Doppler shifts caused by the motion of the eclipse shadow across the ionosphere.

## Times

- Control Day: August 20, 2017, 1400 – 2200 UTC
- Eclipse Day: August 21, 2017, 1400 – 2200 UTC

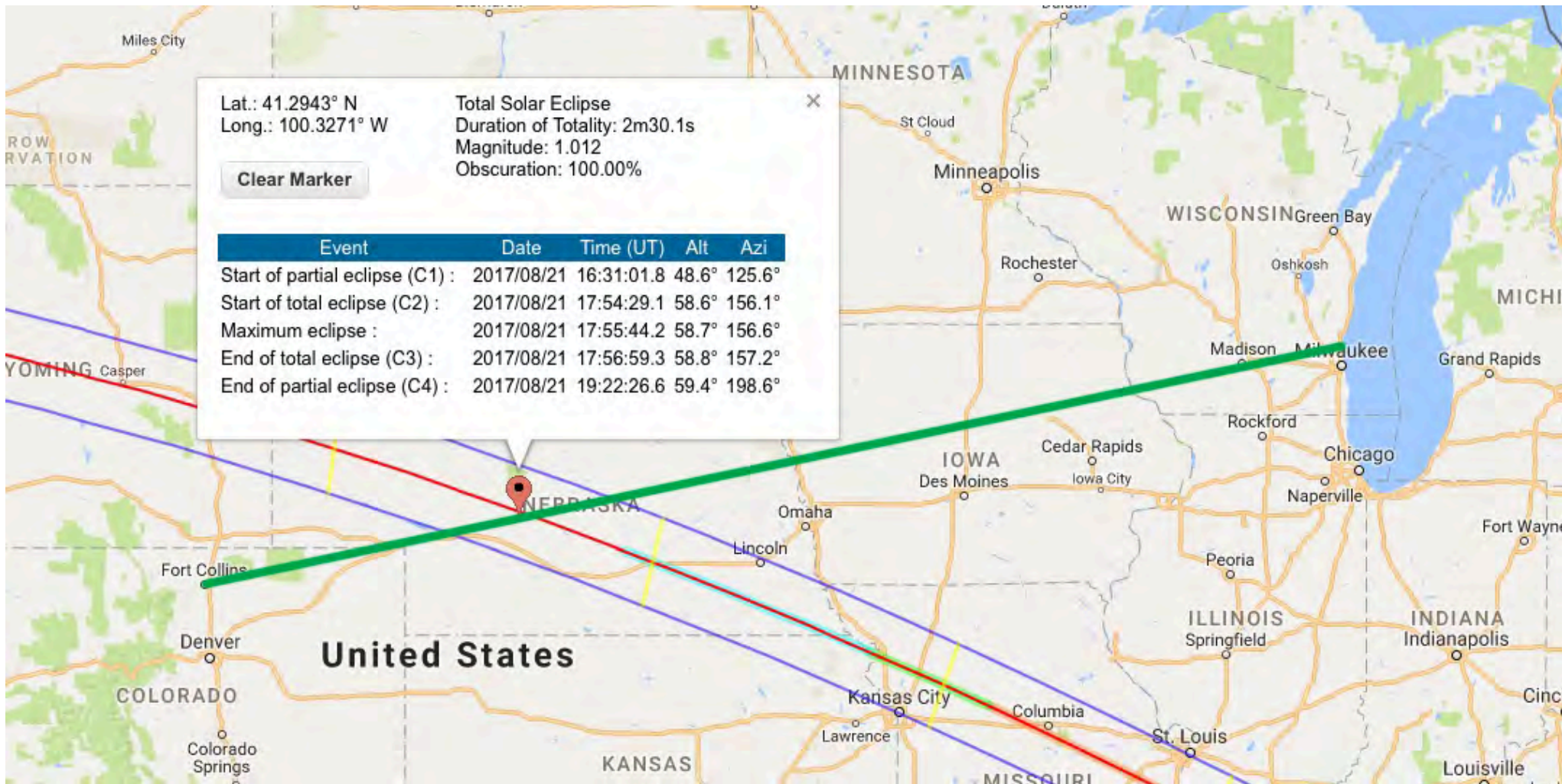
Note: Partial eclipse begins 21 Aug 2017 at about 1600 UTC in Oregon ends at 21 Aug 2017 at about 2015 UTC in South Carolina.

## Beacons

WWV in Fort Collins, CO  
• 2.5 MHz

| Event ( $\Delta T=68.8s$ )    | Date       | Time (UT)  | Alt.   | Azi    | P    | V    |
|-------------------------------|------------|------------|--------|--------|------|------|
| Start of partial eclipse (C1) | 2017/08/21 | 16:23:26.6 | +44.7° | 117.9° | 291° | 12.8 |
| Maximum eclipse (MAX)         | 2017/08/21 | 17:46:43.5 | +56.6° | 144.3° | 020° | 10.4 |
| End of partial eclipse (C4)   | 2017/08/21 | 19:13:48.0 | +61.1° | 185.4° | 108° | 08.5 |

# WA9VNJ 10MHz WWV Observations



(Measurements by Steve Reyer, WA9VNJ)

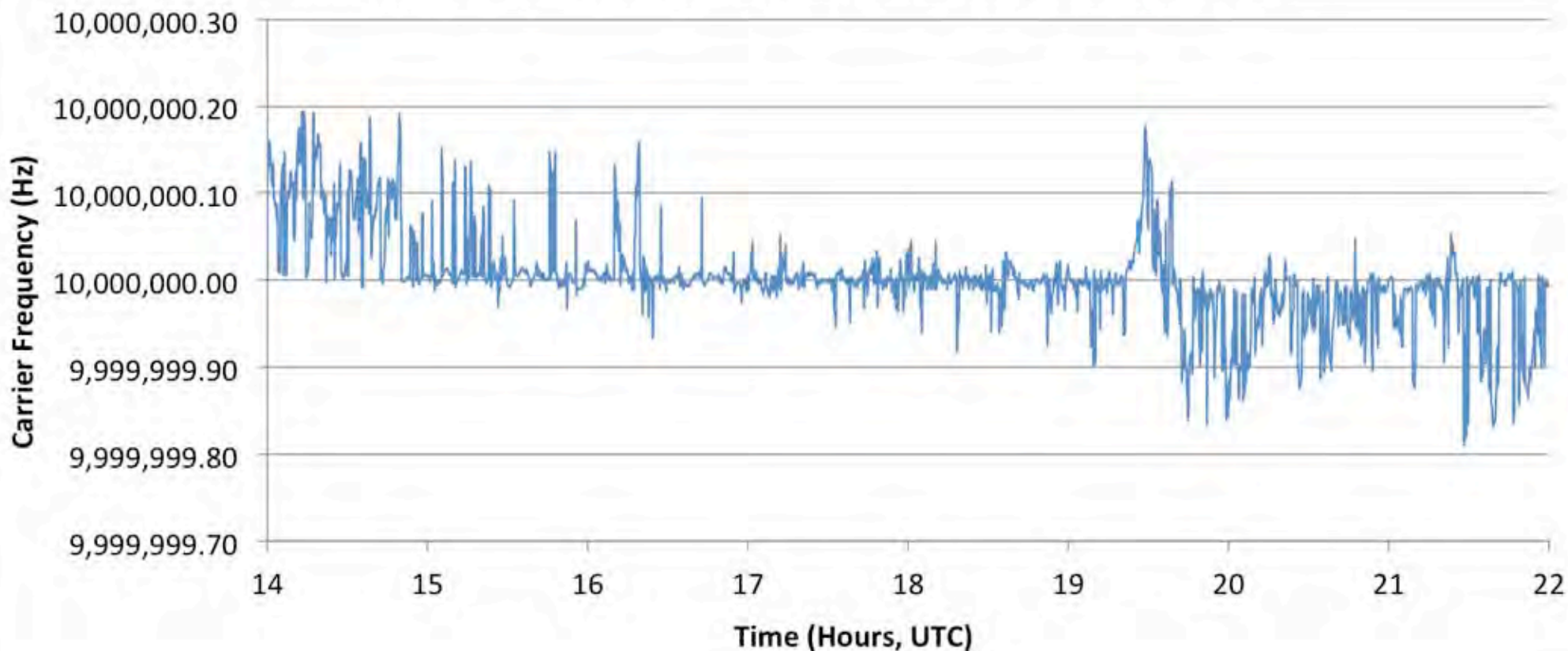
# WA9VNJ Instrumentation

---

- **Radio:** Yaesu FT-857D with XRef-FT oscillator interface driven by a Trimble Thunderbolt GPSDO
- **Calibration:** Rigol DG1022Z signal generator locked to a second TBolt for reference signals.
- **Antenna:** DX Engineering RF-PRO-1B aimed N-S
- **Software:** Spectrum Lab (SL) and custom DSP software.

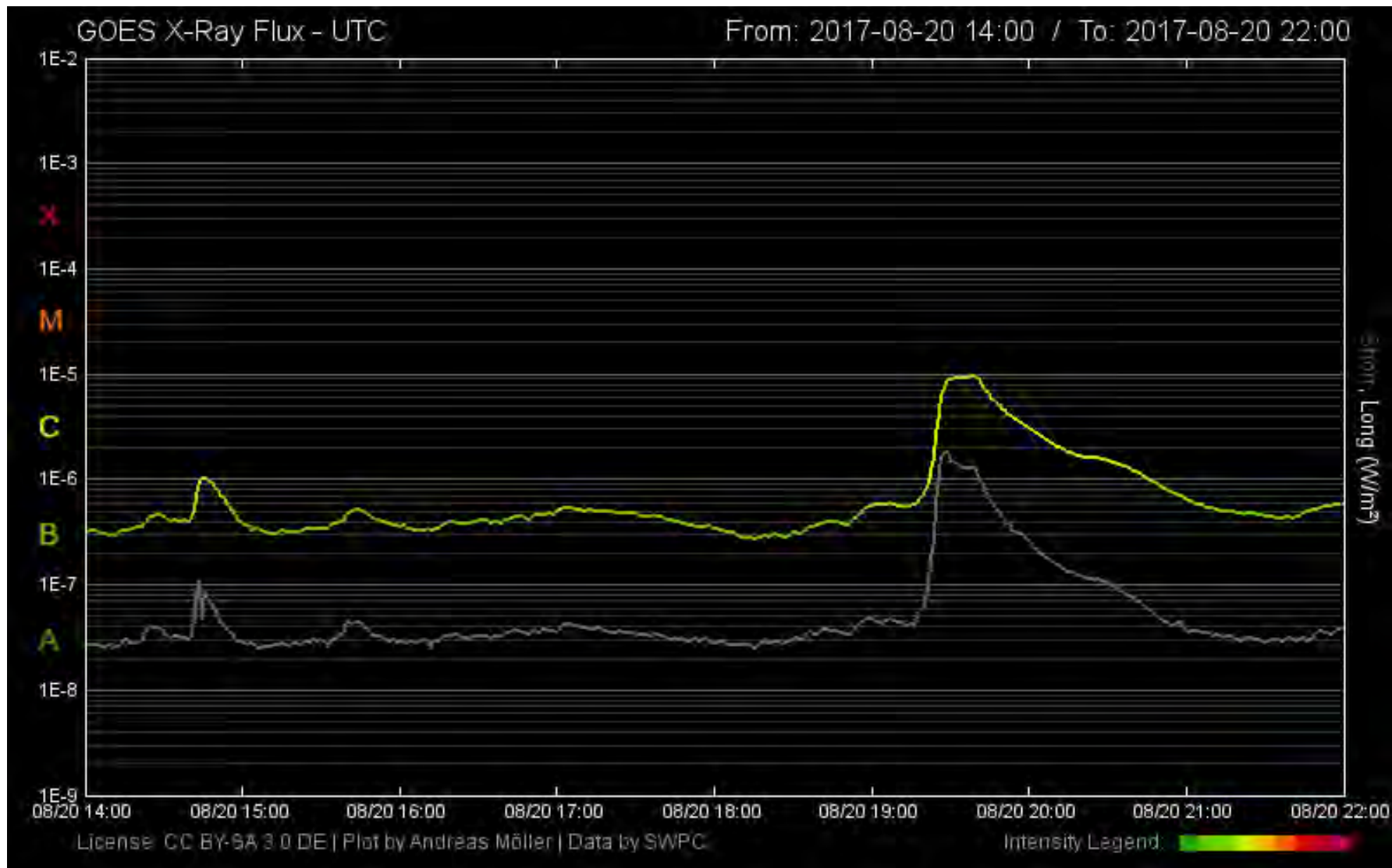
# WA9VNJ 10MHz WWV Observations

WWV 10 MHz Carrier Frequency, 8/20/17 (Control Day)  
Received Near Milwaukee, WI. Mean=10,000,000.0022 Hz





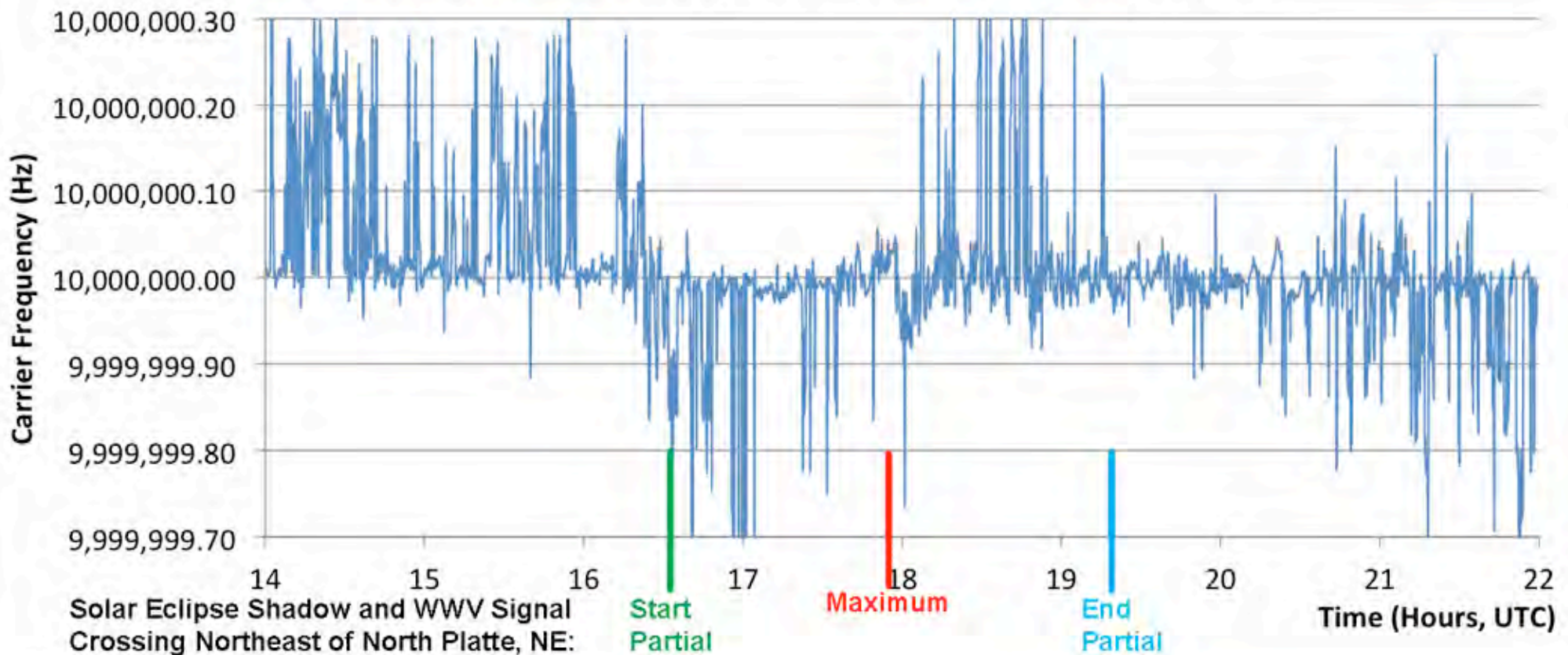
# GOES X-Ray Flux – Control Day



[http://www.polarlicht-vorhersage.de/goes\\_archive](http://www.polarlicht-vorhersage.de/goes_archive)

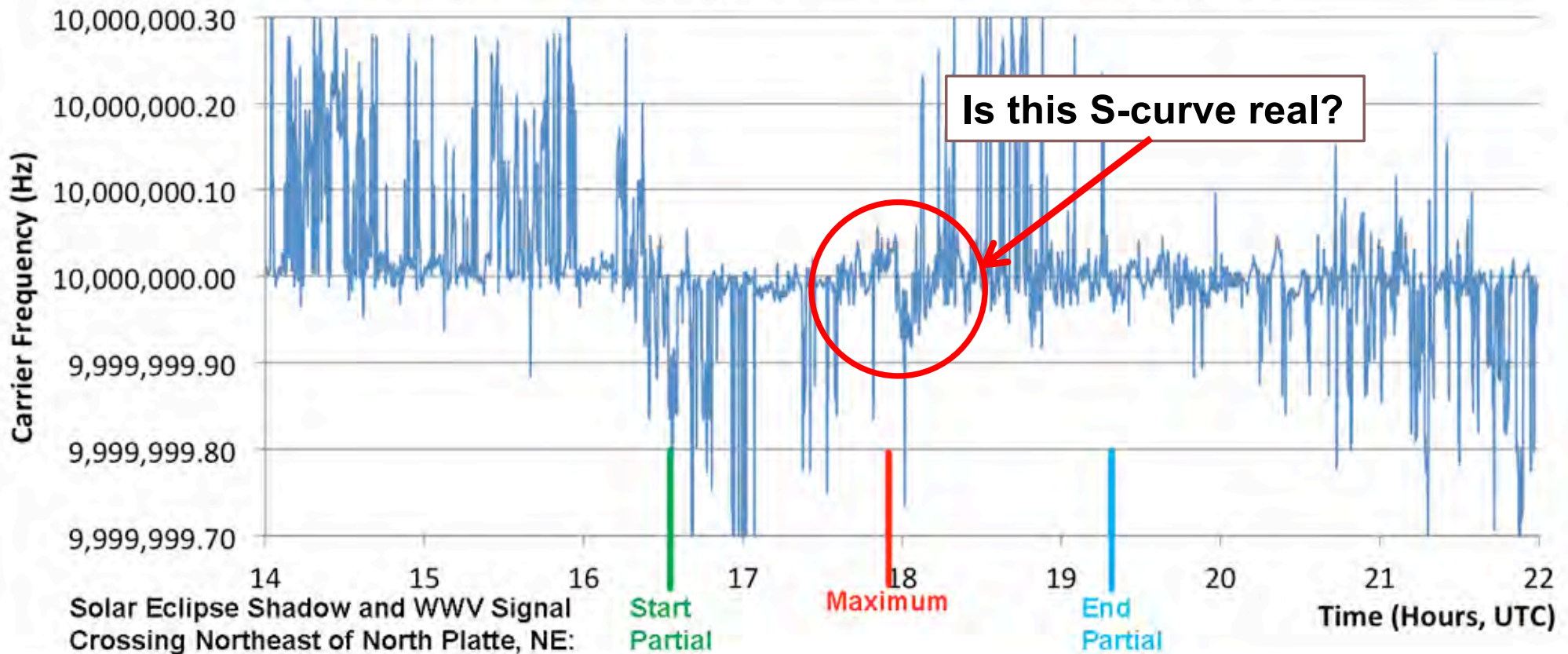
# WA9VNJ 10MHz WWV Observations

WWV 10 MHz Carrier Frequency, 8/21/17 (Eclipse Day)  
Received Near Milwaukee, WI. Mean=10,000,000.0096 Hz

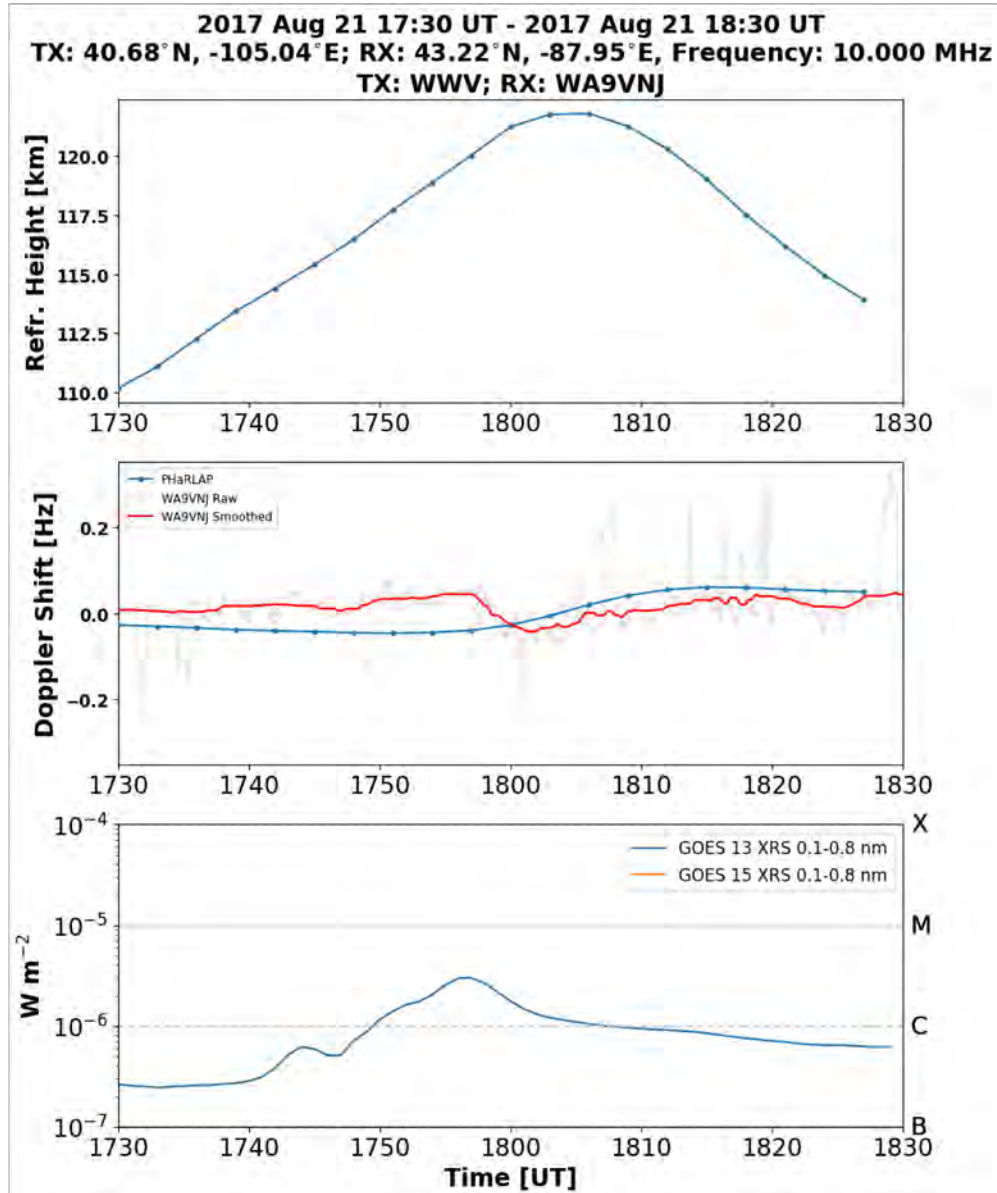


# WA9VNJ 10MHz WWV Observations

WWV 10 MHz Carrier Frequency, 8/21/17 (Eclipse Day)  
Received Near Milwaukee, WI. Mean=10,000,000.0096 Hz



# WA9VNJ/PHaRLAP/GOES



PHaRLAP/SAMI3

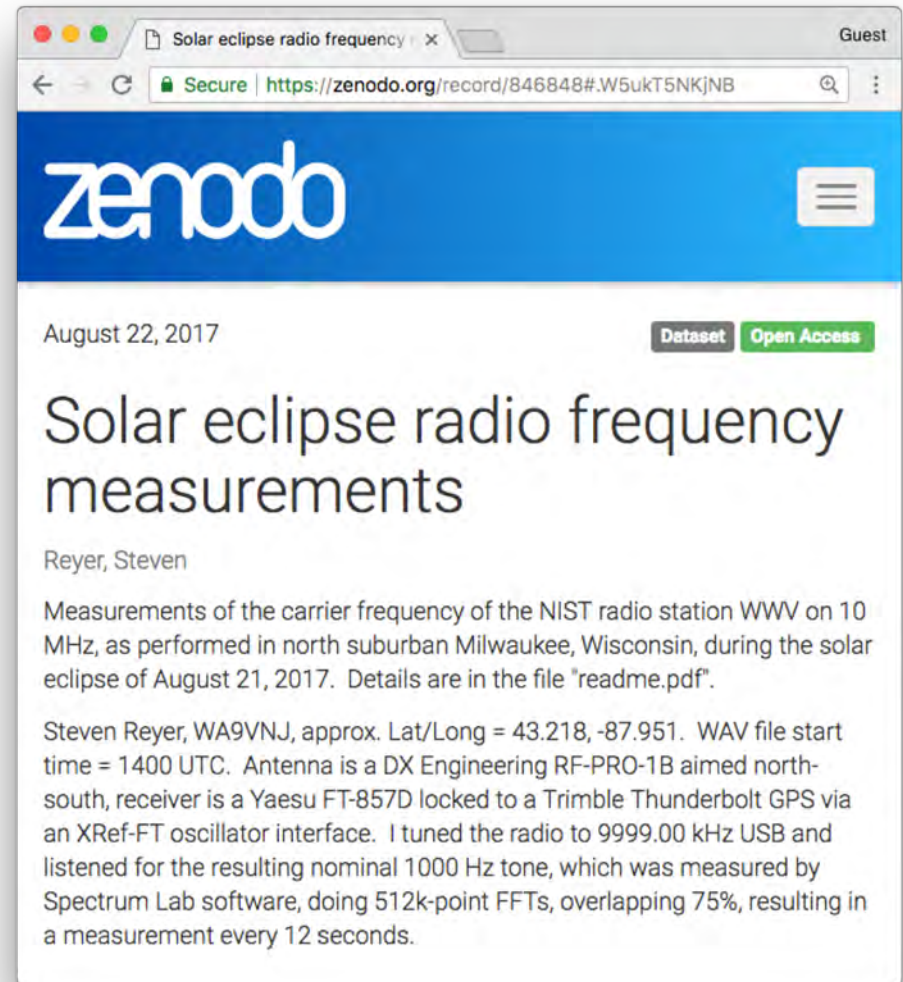
WA9VNJ

PHaRLAP/SAMI3

GOES X-RAY

# WA9VNJ Conclusions

- Doppler shifts observed for
  - Dawn and Dusk
  - Eclipse Onset and Recovery
  - Solar Flares
- Small solar flares can have a pronounced effect
  - C2-Class flare caused 0.05 Hz shift!
- We don't understand the short-term variability.



<https://zenodo.org/communities/hamsci>

# Data Websites



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# Ionogram Data Access

<http://giro.uml.edu/>

GLOBAL IONOSPHERIC RADIO OBSERVATORY


IONOSONDE DATA ONLINE - REALISTIC IONOSPHERE - HARDWARE AND SOFTWARE - DATA TYPES -

  GLOBAL IONOSPHERE RADIO OBSERVATORY  
with Real-Time & Retrospective HF Ionospheric Sounding Data from Lowell  
DIDBase

The Lowell GIRO Data Center (LGDC) implements a suite of technologies for post-processing, modeling, analysis, and dissemination of the acquired and derived data products:

- IRI-based Real-time Assimilative Model, "IRTAM", that builds and publishes every 15-minutes an updated "global weather" map of the peak density and height in the ionosphere, as well as a map of deviations from the classic IRI climate;
- Global Assimilative Model of Bottomside Ionosphere Timelines (GAMBIT) Database and Explorer holding 15 years worth of IRTAM

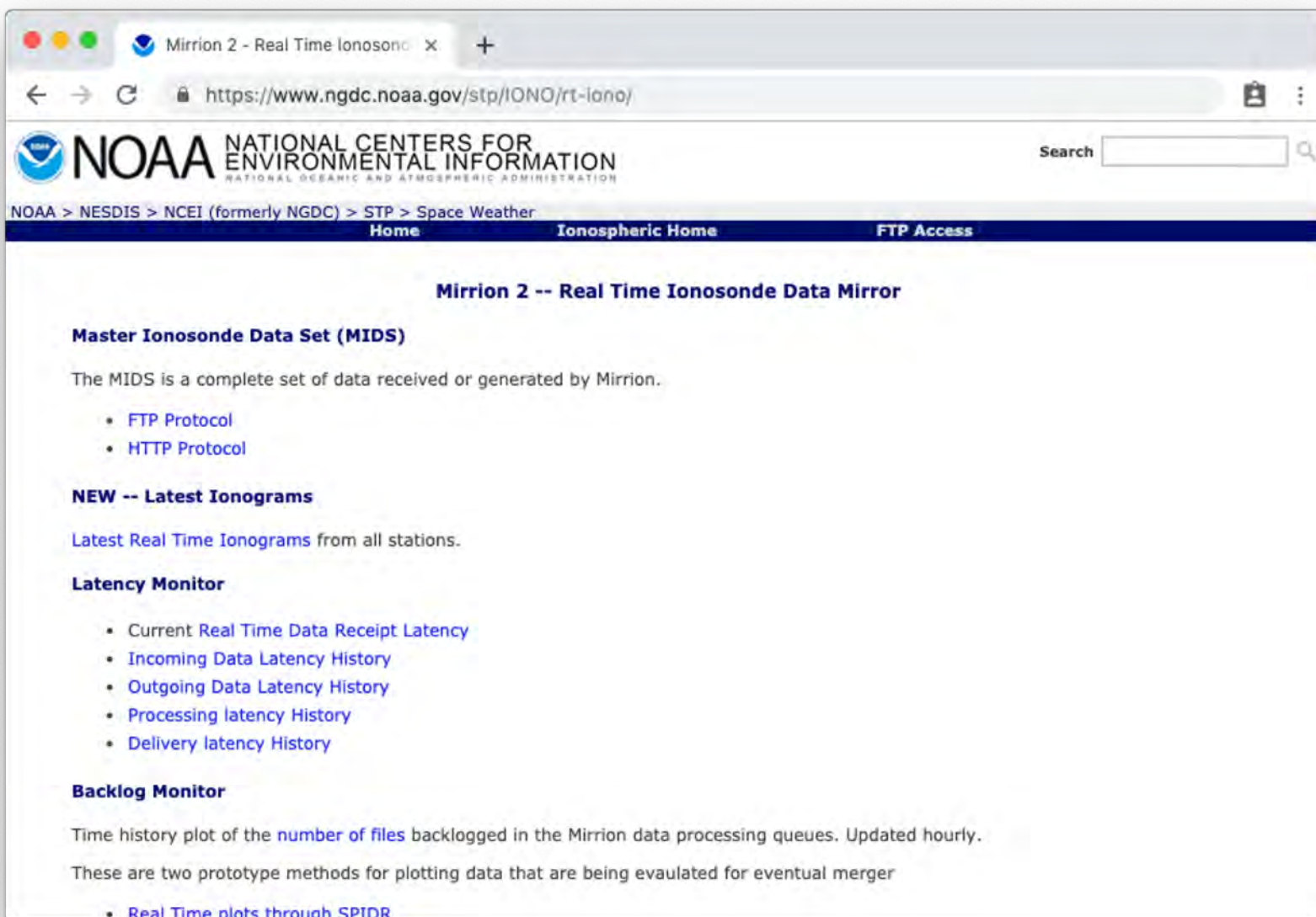
ALL OPERATING AND UPCOMING GIRO SITES:



Legend for map:  
• GIRO Ionosonde real-time  
• IRI-based Real-time Assimilative Model (IRTAM)  
• Retrospective Ionosonde Timelines (GAMBIT)  
• Other IRI-based Assimilative Model

# Ionogram Data Access

<https://www.ngdc.noaa.gov/stp/IONO/rt-iono/>



The screenshot shows a web browser window with the URL <https://www.ngdc.noaa.gov/stp/IONO/rt-iono/>. The page header includes the NOAA logo and the text "NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION" and "NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION". A search bar is visible on the right. The main content area is titled "Mirrion 2 -- Real Time Ionosonde Data Mirror" and contains the following sections:

- Master Ionosonde Data Set (MIDS)**

The MIDS is a complete set of data received or generated by Mirrion.

  - [FTP Protocol](#)
  - [HTTP Protocol](#)
- NEW -- Latest Ionograms**

[Latest Real Time Ionograms](#) from all stations.
- Latency Monitor**
  - [Current Real Time Data Receipt Latency](#)
  - [Incoming Data Latency History](#)
  - [Outgoing Data Latency History](#)
  - [Processing latency History](#)
  - [Delivery latency History](#)
- Backlog Monitor**

Time history plot of the [number of files](#) backlogged in the Mirrion data processing queues. Updated hourly.

These are two prototype methods for plotting data that are being evaluated for eventual merger

  - [Real Time plots through SPIDR](#)



# ISR & GPS TEC Data

<http://cedar.openmadrigal.org>

Madrigal database at CEDAR

cedar.openmadrigal.org

CEDAR Home Access data Access metadata Run models Documentation Other Madrigal sites

OpenMadrigal

## Welcome to the Madrigal CEDAR Database

Madrigal is an upper atmospheric science database used by groups throughout the world. Madrigal is a robust, World Wide Web based system capable of managing and serving archival and real-time data, in a variety of formats, from a wide range of upper atmospheric science instruments. Data at each Madrigal site is locally controlled and can be updated at any time, but shared metadata between Madrigal sites allow searching of all Madrigal sites at once from any Madrigal site.

To see a list of all Madrigal sites, use the *Other Madrigal sites* pull down menu. Data can also be accessed directly, using [APIs](#) which are available for several popular programming languages (Matlab, python, and IDL). A Subversion archive of all Madrigal software and documentation is available from the [Open Madrigal Web site](#). The latest version of Madrigal and the remote API's may also be downloaded from there.

Use of the Madrigal Database is generally subject to the CEDAR Rules-of-the-Road . Prior permission to access the data is not required. However, the user is required to establish early contact with any organization whose data are involved in the project to discuss the intended usage. Data are often subject to limitations which are not immediately evident to new users. Before they are formally submitted, draft copies of all reports and publications must be sent to the contact scientist at all data-supplying organizations along with an offer of co-authorship to scientists who have provided data. This offer may be declined. The Database and the organizations that contributed data must be acknowledged in all reports and publications, and whenever this data is made available through another database. If you have any questions about appropriate use of these data, contact [brideout@haystack.mit.edu](mailto:brideout@haystack.mit.edu)

# SuperDARN Data Access

<http://vt.superdarn.org>

The screenshot shows the SuperDARN website interface. At the top, there is a navigation bar with the Virginia Tech logo and 'College of Engineering'. Below this is the 'Space@VT SuperDARN' logo. A search bar is located on the right. The main content area features two maps of the Northern Hemisphere showing radar coverage areas in various colors (orange, green, blue). A 'Welcome to SuperDARN!' message is displayed below the maps, explaining that the network consists of more than 30 low-power HF radars. A sidebar on the left contains a menu with categories: SuperDARN (News, SD Working Groups, SD Pub List, SD Documents, SD Tech News, SD-Van Allen Probes, Space Weather Portal), VT SuperDARN (Personnel, Contact/Visit Us, VT Pub List, Tutorials, Student Opportunities, Group Meetings), Radars (Maps/Tables/Links, Operating Schedule, Radar Coverage Tool, Conjugate FOV Tool, Radar Finder, Ray-Tracing Tool), Software, and SuperDARN Data (Real Time Data).

# Thank you!

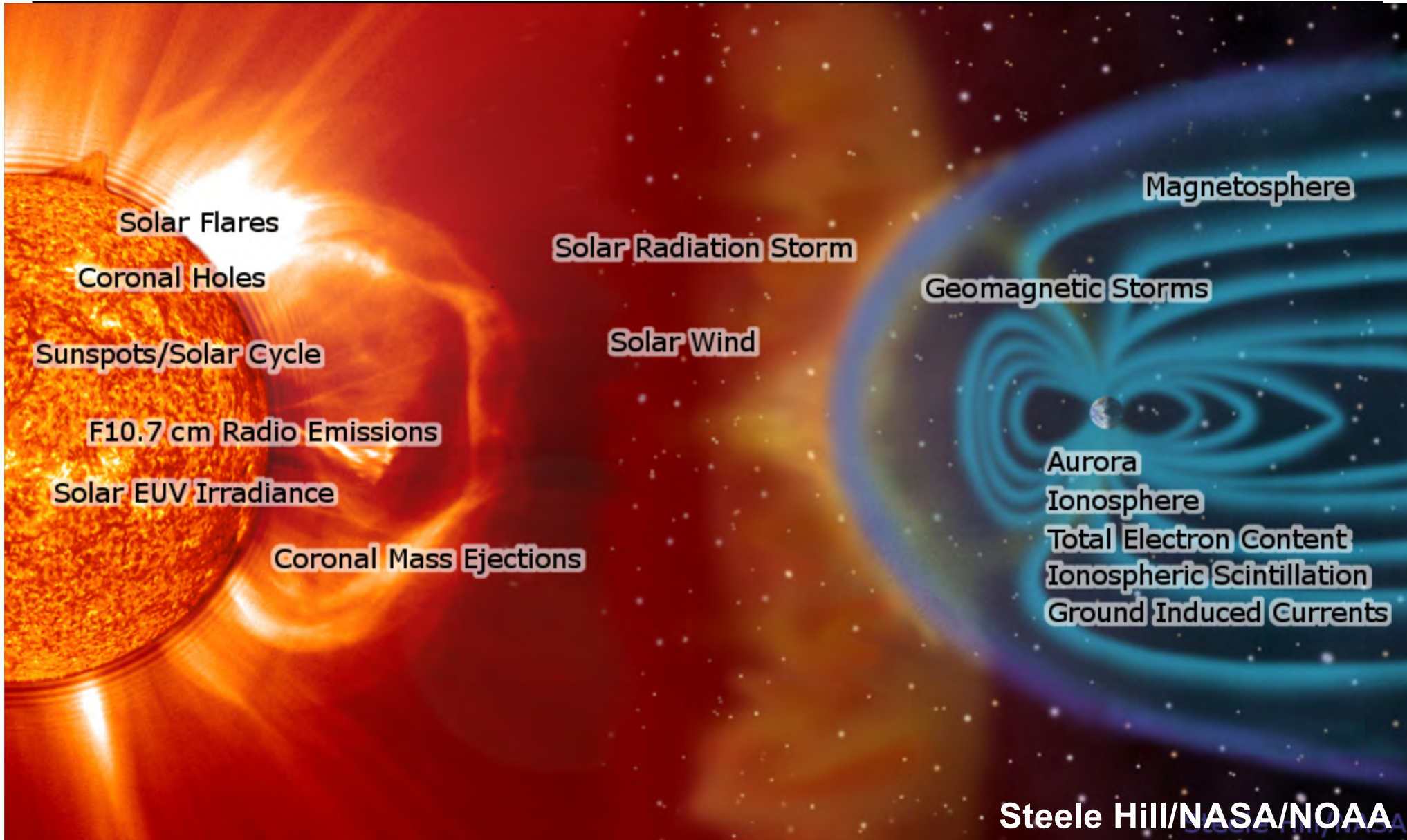
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# Acknowledgements

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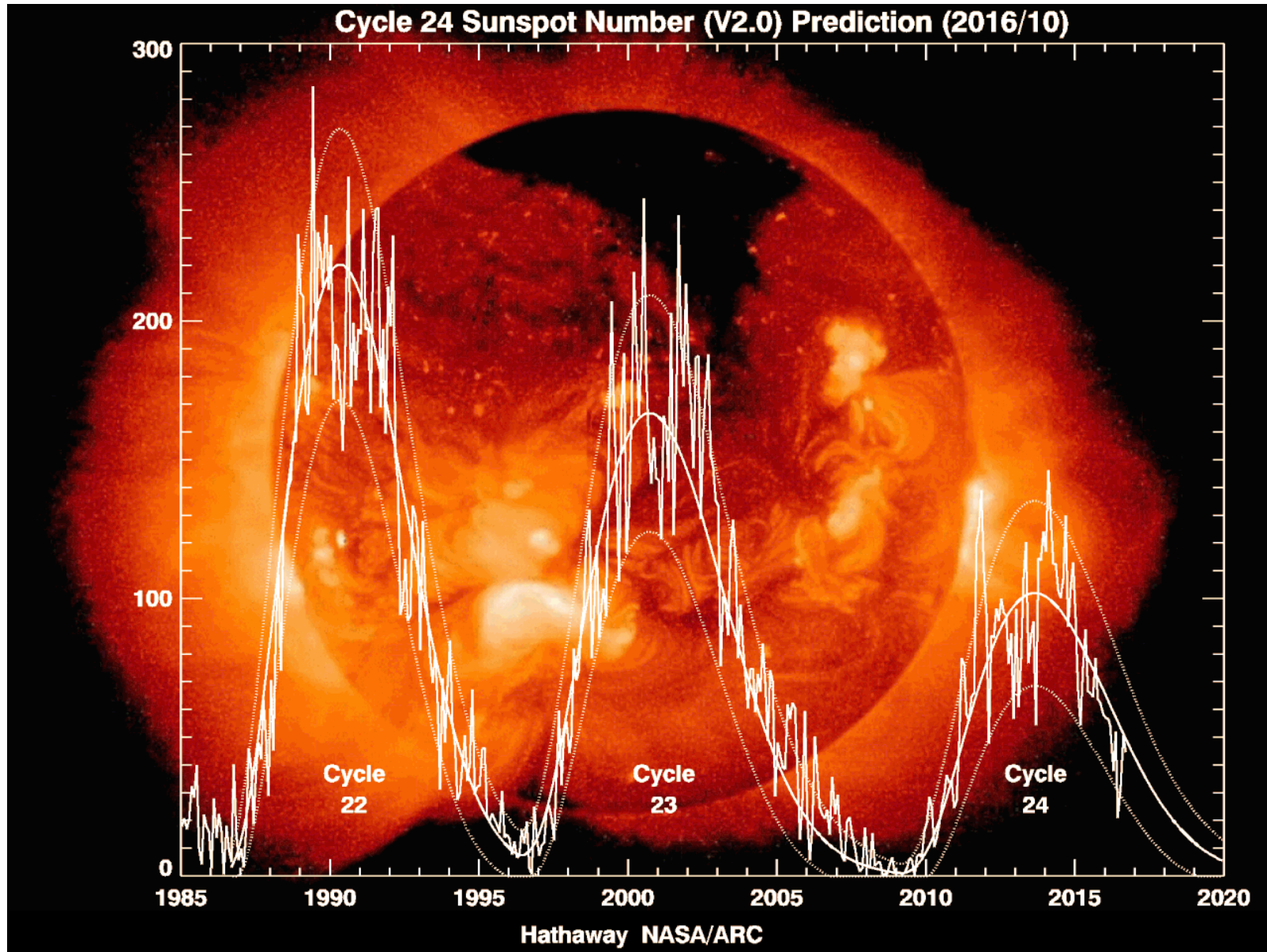
- Space Weather Effects on Radio Communication and GNSS Lecture by Geoff Hughes, 2018 Boulder Space Weather Summer School
- UNIS Lectures on Ionospheric Radars by Kjellmar Oksavik and Katie Herlingshaw
- Arecibo Heating Antenna HamSCI Workshop 2019 presentation by Jim Breakall
- Other sources as referenced

# Solar-Terrestrial Environment

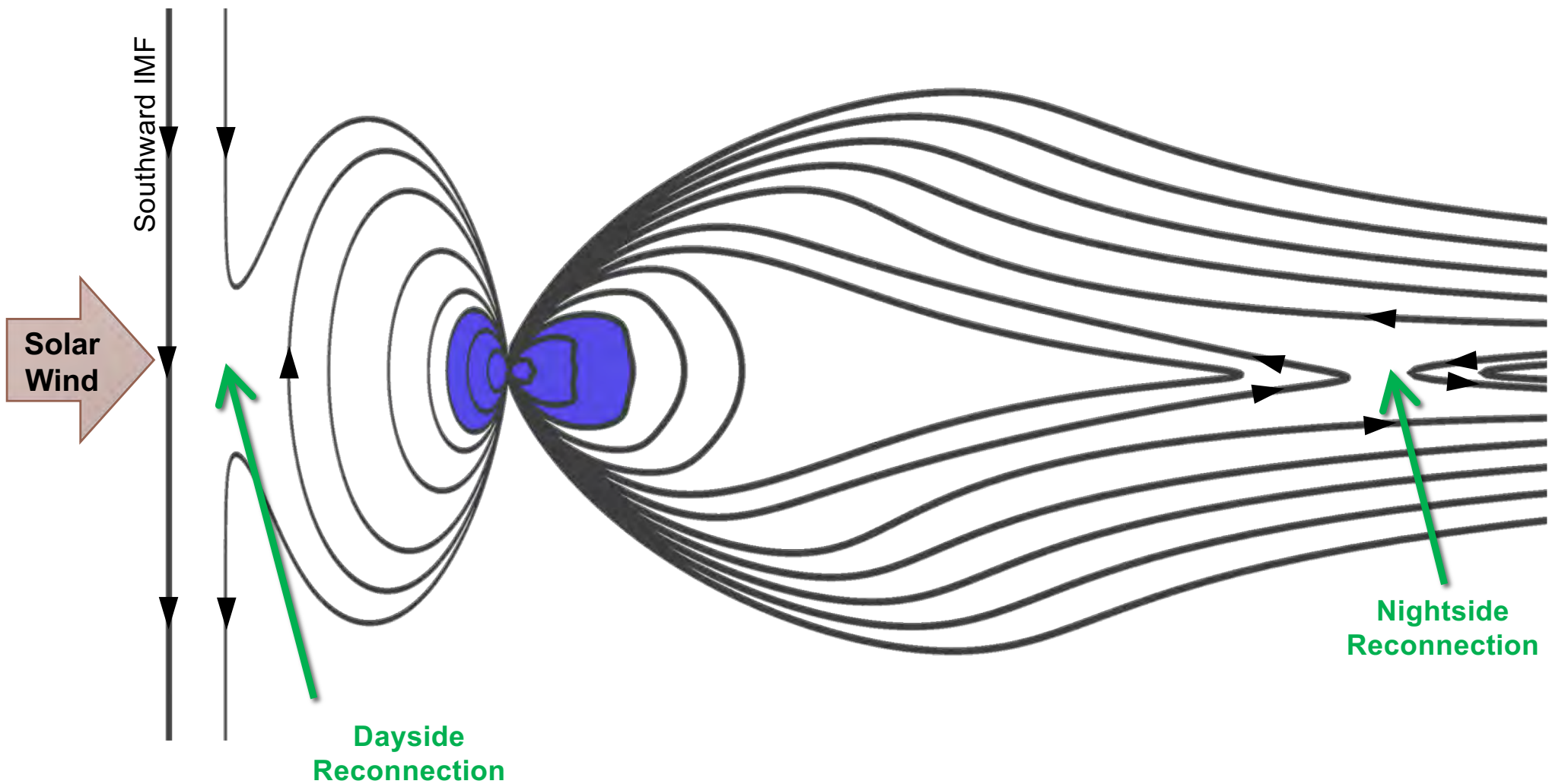


Steele Hill/NASA/NOAA

# Sunspot Cycle

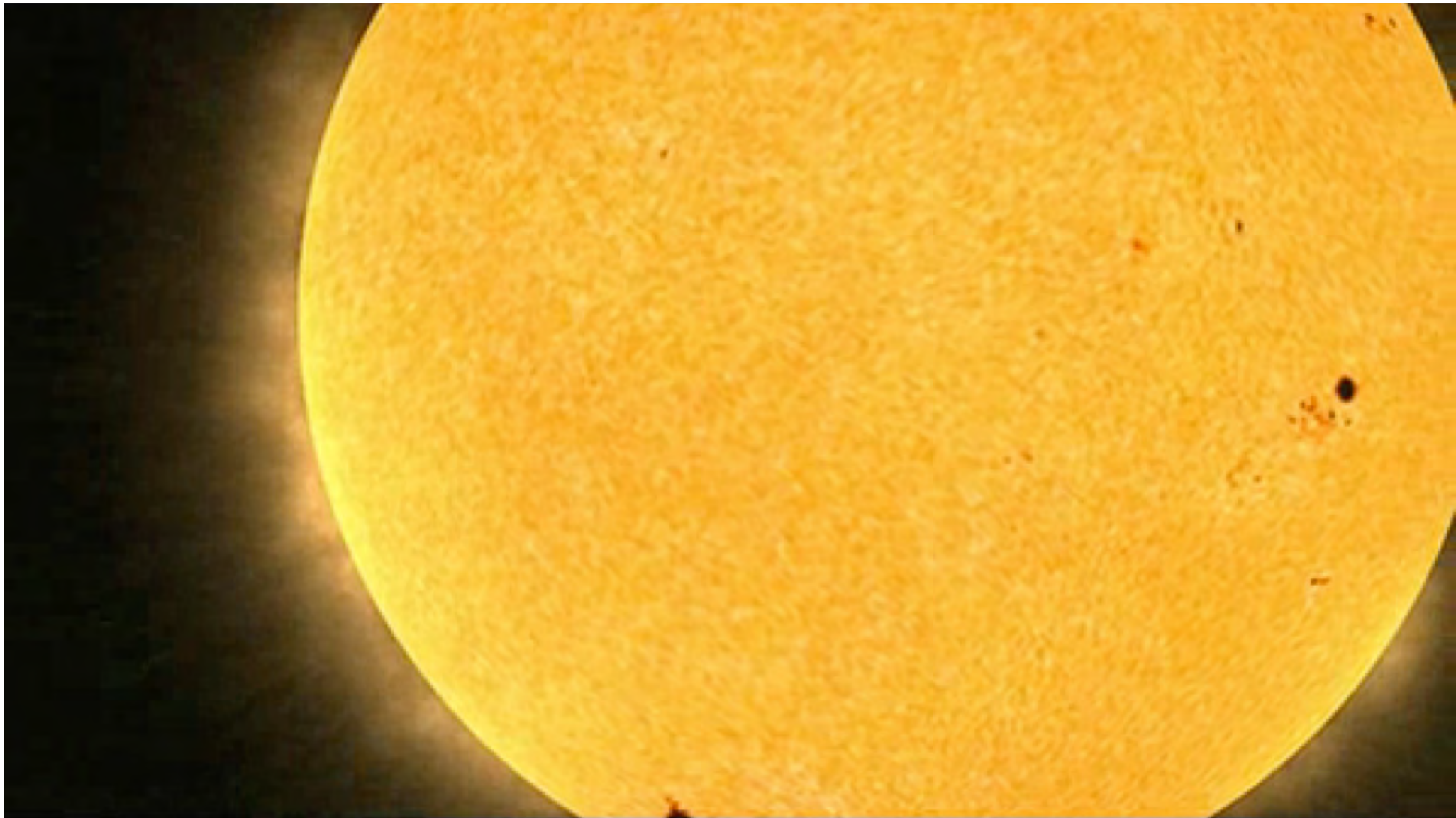


# Getting Energy into the Magnetosphere



[Frissell, 2016, Dissertation]

# Substorms



[Visualization by NASA]

HamSci  
<http://hamsci.org>

NJIT

frissell@njit.edu



# NOAA Space Weather Prediction Center

Homepage | NOAA / NWS Space Weather Prediction Center | nafri...@gma...

www.swpc.noaa.gov

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

NATIONAL WEATHER SERVICE

SPACE WEATHER PREDICTION CENTER  
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Sunday, February 04, 2018 21:00:38 UTC

HOME ABOUT SPACE WEATHER PRODUCTS AND DATA  
MEDIA AND RESOURCES SUBSCRIBE ANNUAL MEETING

**SPACE WEATHER CONDITIONS** on NOAA Scales

24-Hour Observed Maximums

|           |           |           |
|-----------|-----------|-----------|
| R<br>none | S<br>none | G<br>none |
|-----------|-----------|-----------|

Latest Observed

|           |           |           |
|-----------|-----------|-----------|
| R<br>none | S<br>none | G<br>none |
|-----------|-----------|-----------|

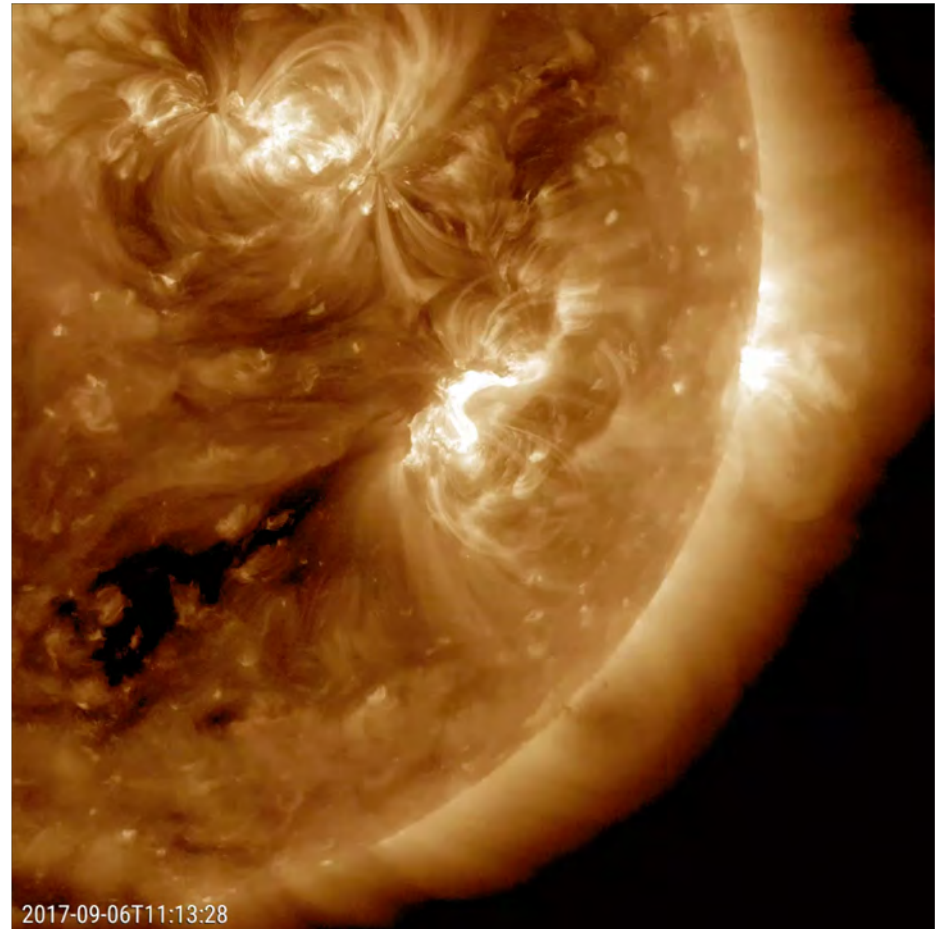
Solar Wind Speed: **379** km/sec    Solar Wind Magnetic Fields: Bt **5** nT, Bz **0** nT  
Noon 10.7cm Radio Flux: **73** sfu

**Global Scale Predictions**

- Radio Blackouts
- Solar Radiation Storms
- Geomagnetic Storms

# Solar Flares

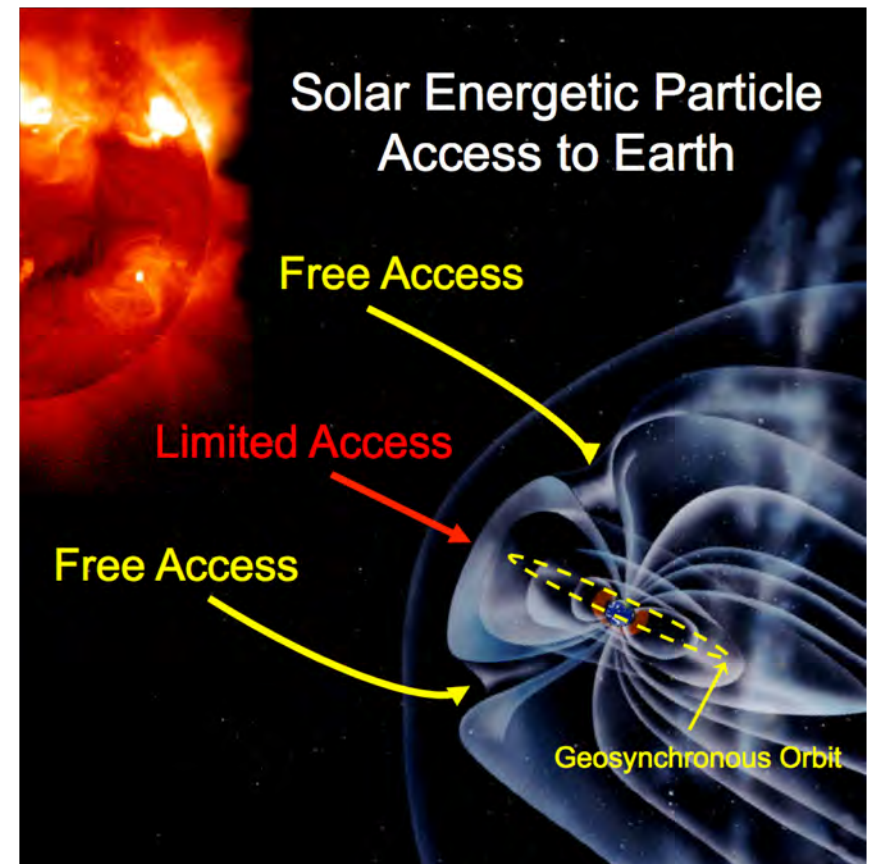
- Sudden increase in electromagnetic energy from localized regions on the sun.
- Energy travels at the speed of light (8 min to Earth)
- Soft X-Ray (0.1-0.8 nm) Earthward-directed energy can cause HF radio blackouts.
- Often, but not always, accompanied by a CME.



NASA SDO Observation of X9.3  
Solar Flare on Sept 6, 2017

# Solar Radiation Storm

- Large-scale magnetic eruption on the sun accelerates charged particles to very high velocities.
- Associated with CMEs or Solar Flares
- Accelerated protons are most important
  - 1/3 speed of light (100,000 km/s)
  - 15 min to hours to reach Earth
- Guided by field lines into polar regions.
- Lasts for hours to days

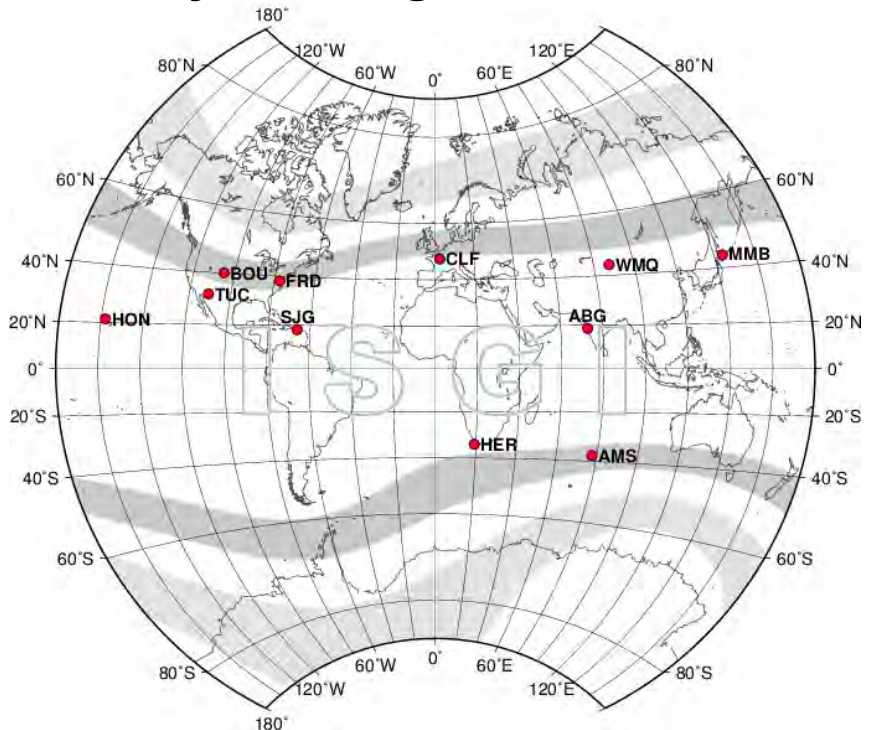


[NASA / Annotated by H. Singer]

# Geomagnetic Storms

- Fast CMEs and CIR/HSSs can lead to geomagnetic storms.
- Requires efficient energy exchange between solar wind and magnetosphere (extended periods of southward  $B_z$  and high-speed solar wind).
- Defined by negative excursion in Dst/Sym-H indices.

## Sym-H Magnetometers



[http://isgi.unistra.fr/indices\\_asy.php](http://isgi.unistra.fr/indices_asy.php)

