Ionospheric Propagation Dynamics Studied with Pactor

Ed Jones (AE4TM)

November 2, 2006

Collaborators

Harold C. Diezel (W7KP)
Telecommunications Engineer, Fallon, NV 89406

Raymond A. Greenwald, PhD
Director of SuperDARN OTHR Program
Applied Physics Laboratory
The Johns Hopkins University, Laurel, MD 20723

Hans-Peter Helfert (DL6MAA)
Special Communications Systems GmbH & Co. KG
Roentgenstr 36, 63454 Hanau, Germany

Murray K. Woodfield (ZL1CN)
Wellsford, Auckland 1242
182 Ingleton Road
New Zealand

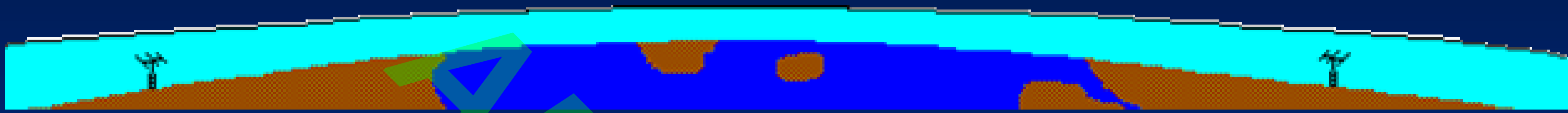
Mode Requirements

1) High sensitivity (Pactor has -18 dB S/N sensitivity - inaudible)
2) Provide accurate time delay readings (Pactor accuracy is 0.625mS)
3) Provide accurate relative Doppler shifts (Pactor accuracy is 35mHz)

HF Station Requirements

1) Consistent readings from HF transceivers (ICOM-746 and Rohde-Schwarz XK-2100)
2) Highest gain with minimum directivity
3) Base stations utilized Zepp antennas
4) Mobile stations utilized all-bander SG-303 verticals with SG-231 autotuners

Establishing a Pactor Contact

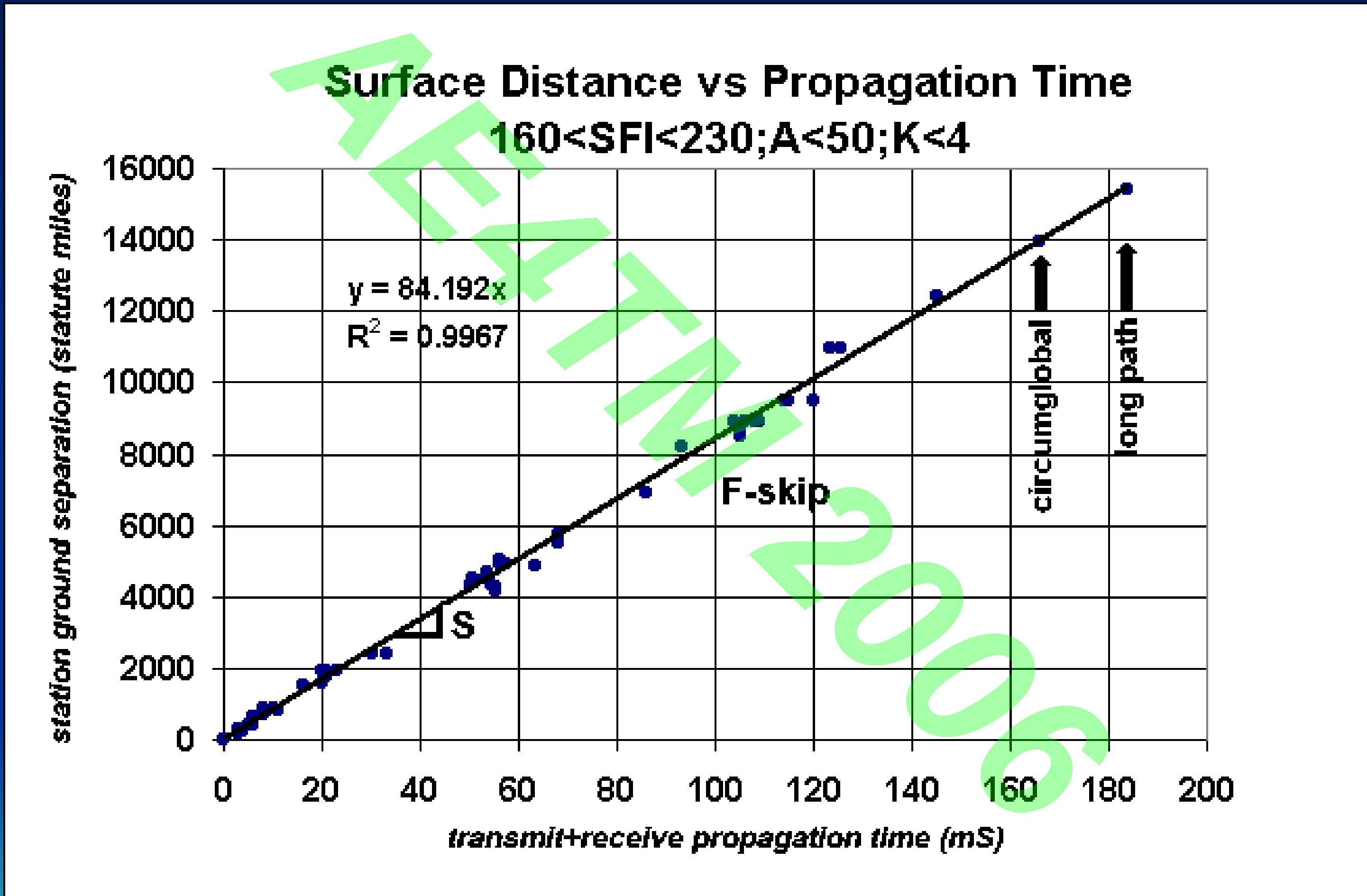


1) Master station ae4tm-1 sends a connect request to a monitoring slave station, e.g. C ae4tm-2.
2) If heard by slave station ae4tm-2, an "ack" is returned.
3) The Pactor controllers begin error free CRC handshaking.
4) The propagation time delay is recorded for error corrections (this data is available for propagation time calculations).
5) The relative frequency difference is updated with each packet burst for the error correction (this data is available for experiments).

Calculating Propagation Distance

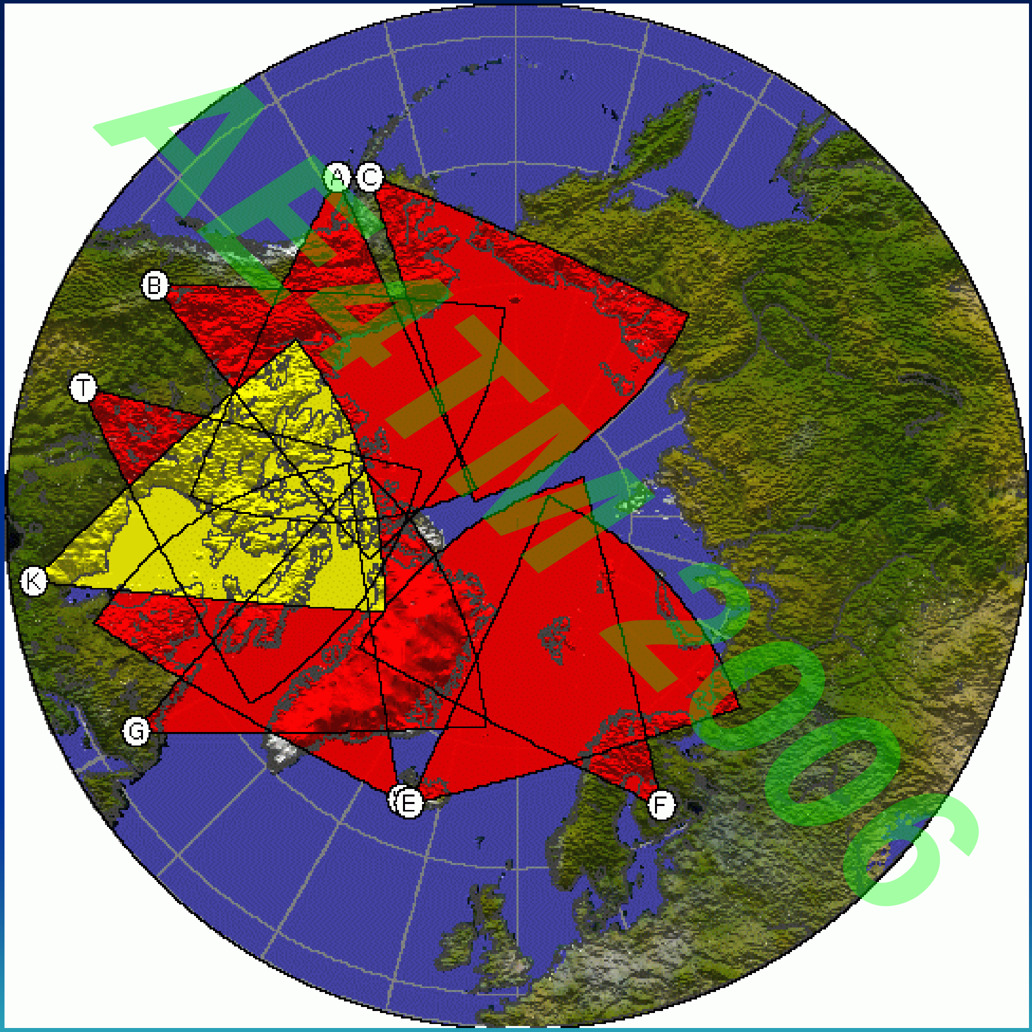
- Must subtract time delay from the station electronics: typical delays ~ 55mS.
- Delay (mS) = 21mS + CSD(mS) + IRD_m + IRD_s
- Typical IRD = 3.0mS (SSB IF) – 4.5mS (CW IF)
- D (miles) = 186 mi/mS X t (mS) / 2 (full distance)
- D (miles) = 186 mi/mS X t (mS) / 4 (radar mode)
- $V_{Doppler}$ = (c / 2) X (Δf / f)

Propagation Times



Collaboration with SuperDARN

Kapuskasing SuperDARN Station



Blind (Skip) Zone

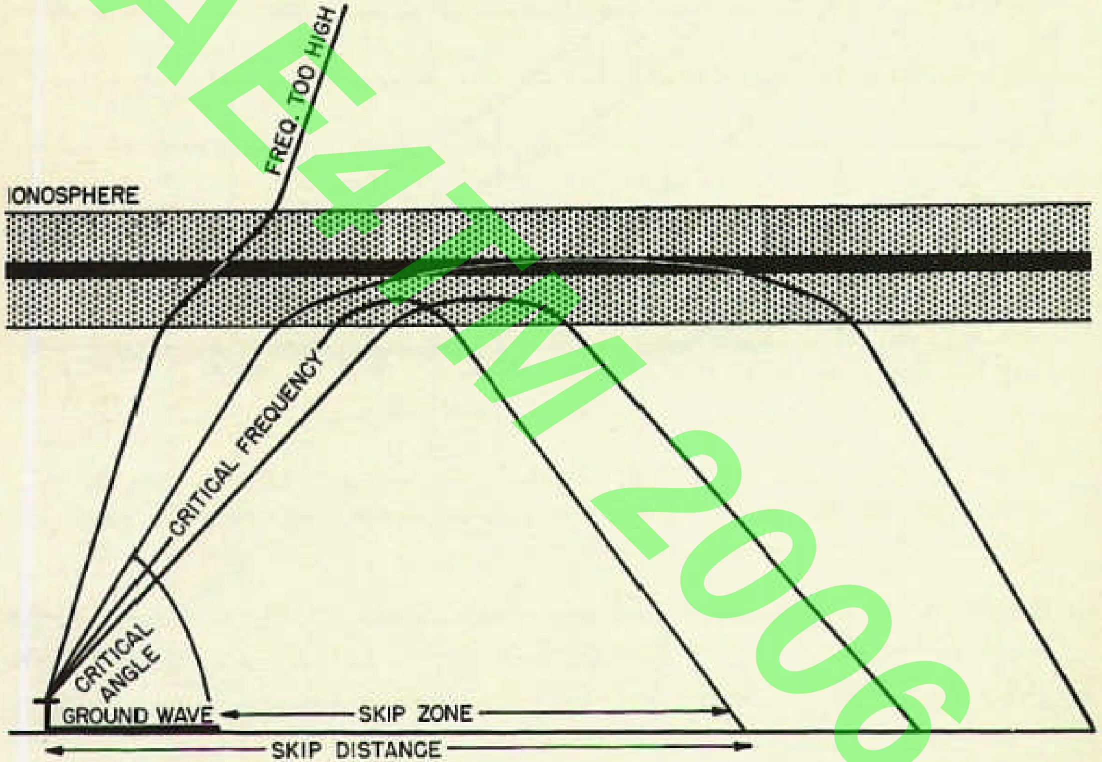
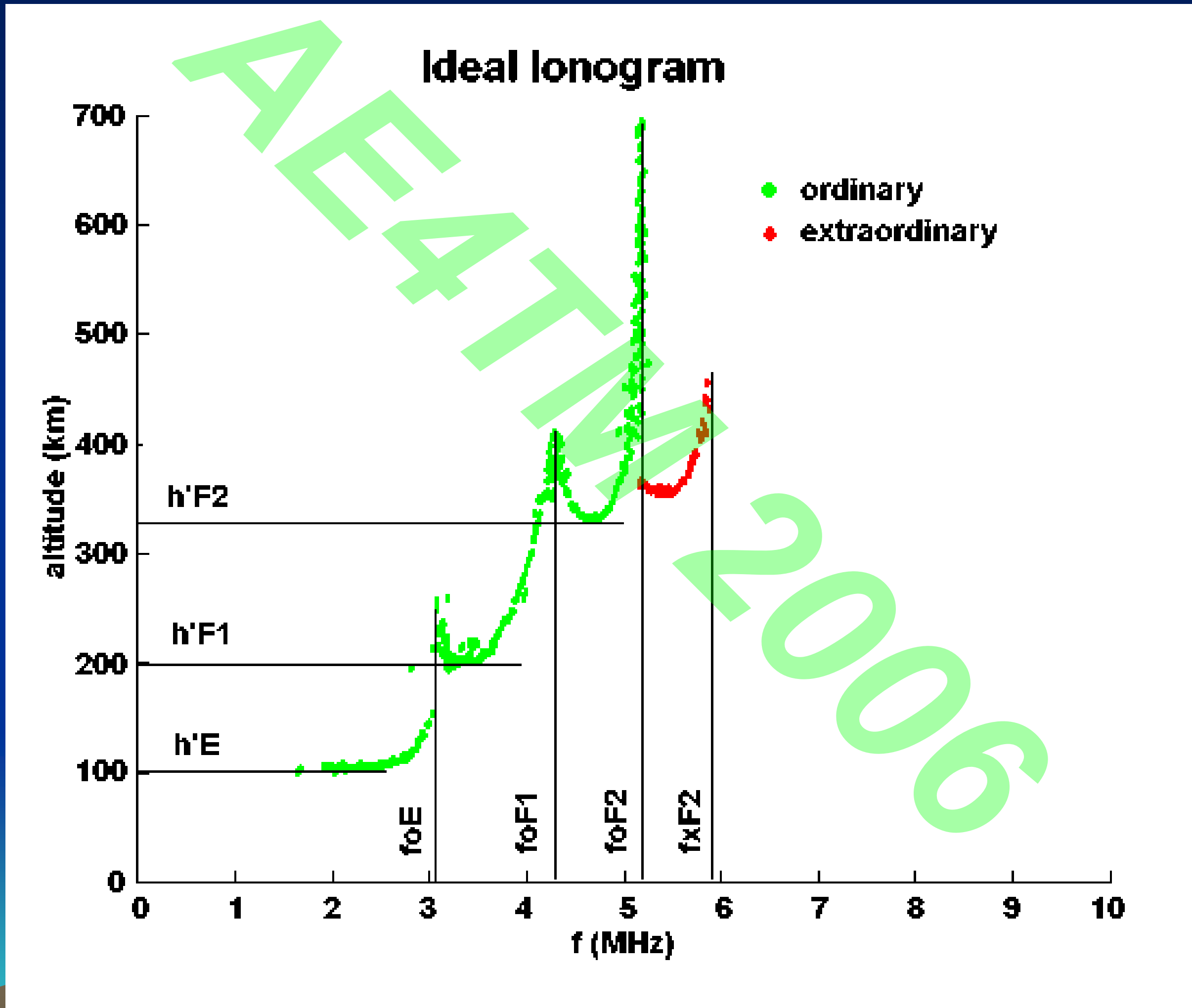


Fig. 7-4. Differing sky-wave paths.

Ideal Ionogram



Interpreting Ionograms

$N_{max} = 1.24 \times 10^{10} \, (f_o^{\,2} \pm f_o f_\omega) \; m^{-3}$, where

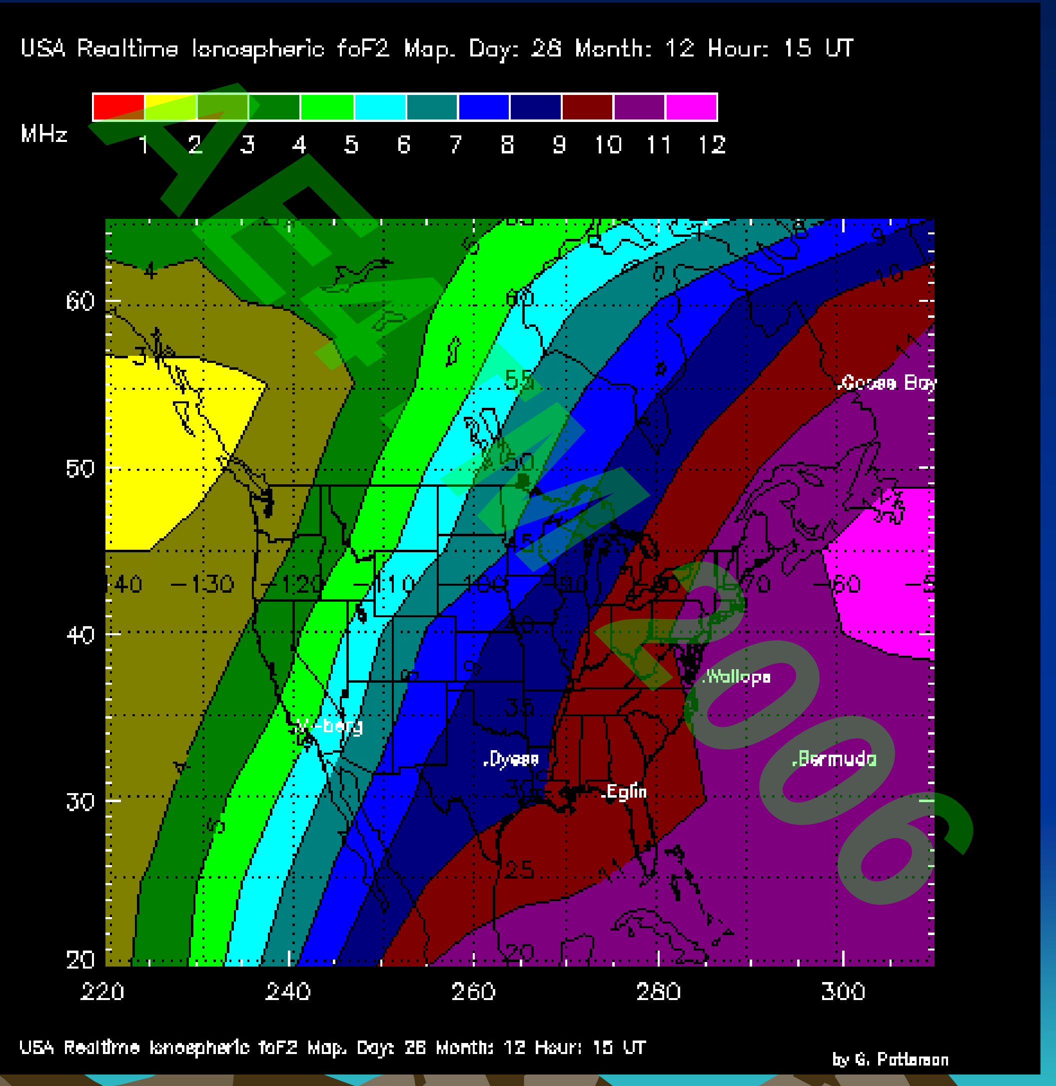
N_{max} is the peak electron density per m^{-3} ,

f_o is the frequency in MHz, and

f_ω is the plasma frequency ($\sim 10^6 \, s^{-1} - 10^7 \, s^{-1}$).

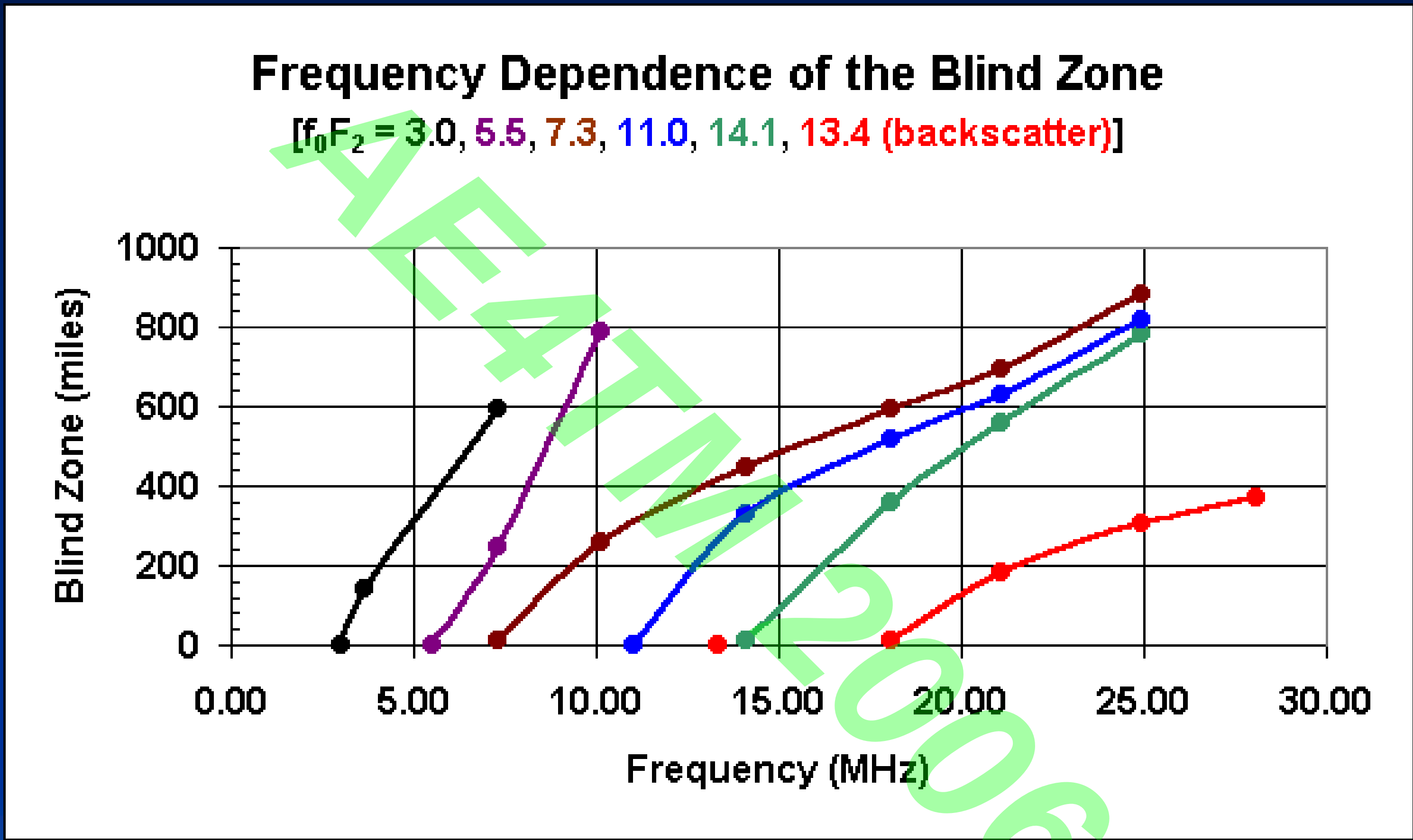
Note: $\pm$ represents the ordinary and extraordinary modes.

f_oF2 Maps



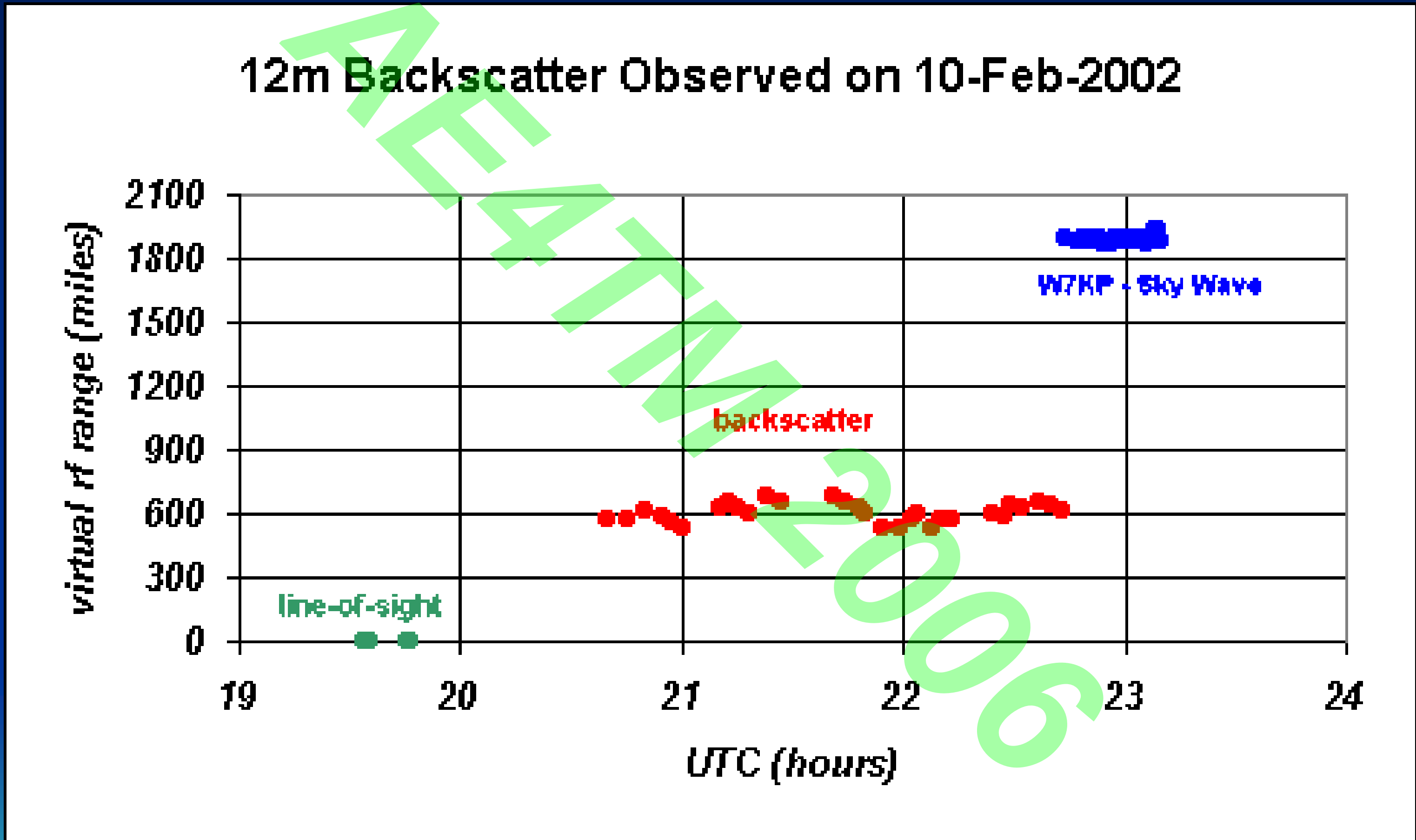
USA Realtime Ionospheric foF2 Map. Day: 28 Month: 12 Hour: 15 UT
MHz
1 2 3 4 5 6 7 8 9 10 11 12
60
50
40
30
20
220
240
260
280
300
.Goose Bay
.Wallops
V-berg
.Dyess
.Eglin
.Bermuda
USA Realtime Ionospheric foF2 Map. Day: 28 Month: 12 Hour: 15 UT
by G. Patterson

Frequency Dependence of HF Blind Zone

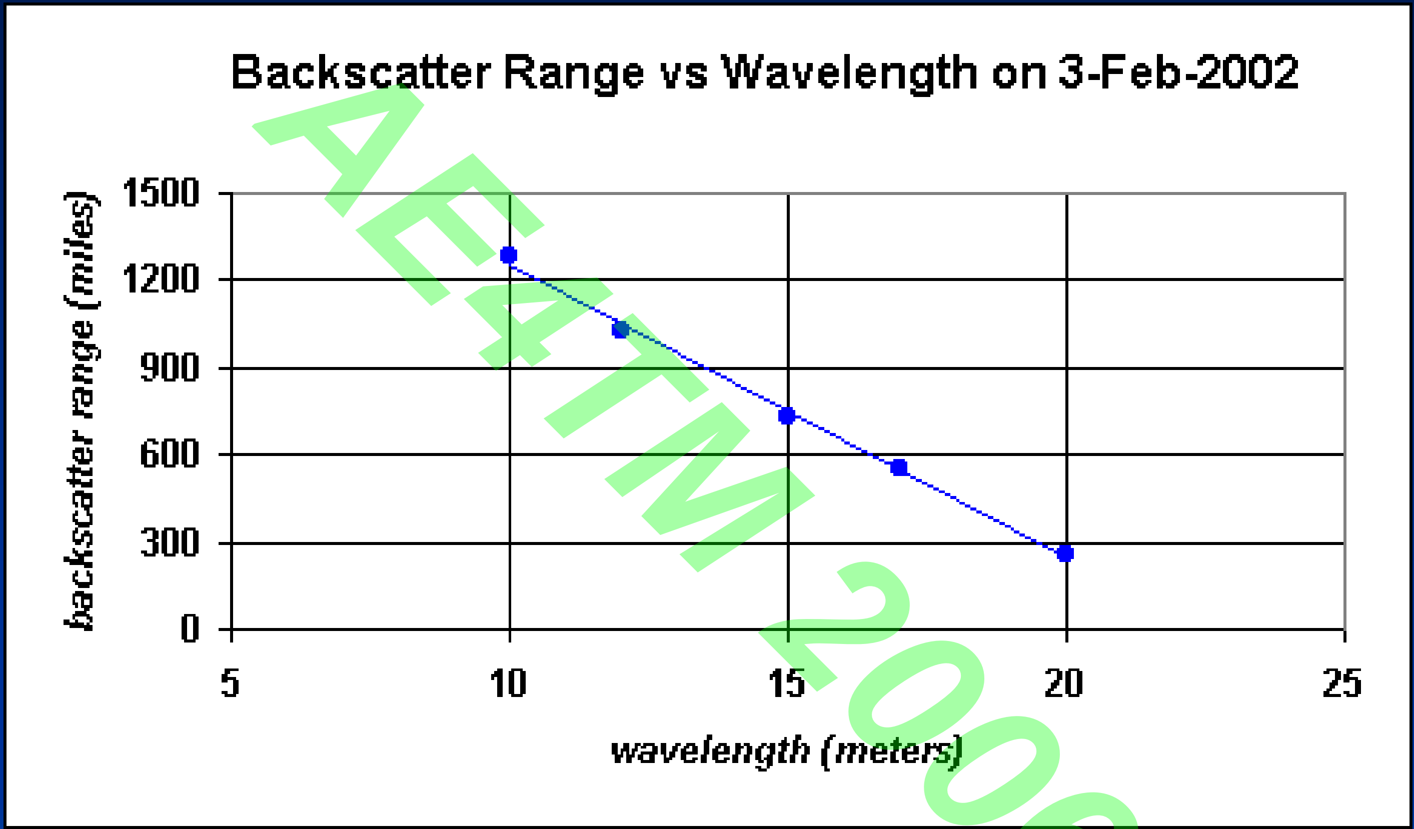


Blind Zone (mi) ~ 730 LN [f / foF2] +78

HF Backscatter ("*long skip*")

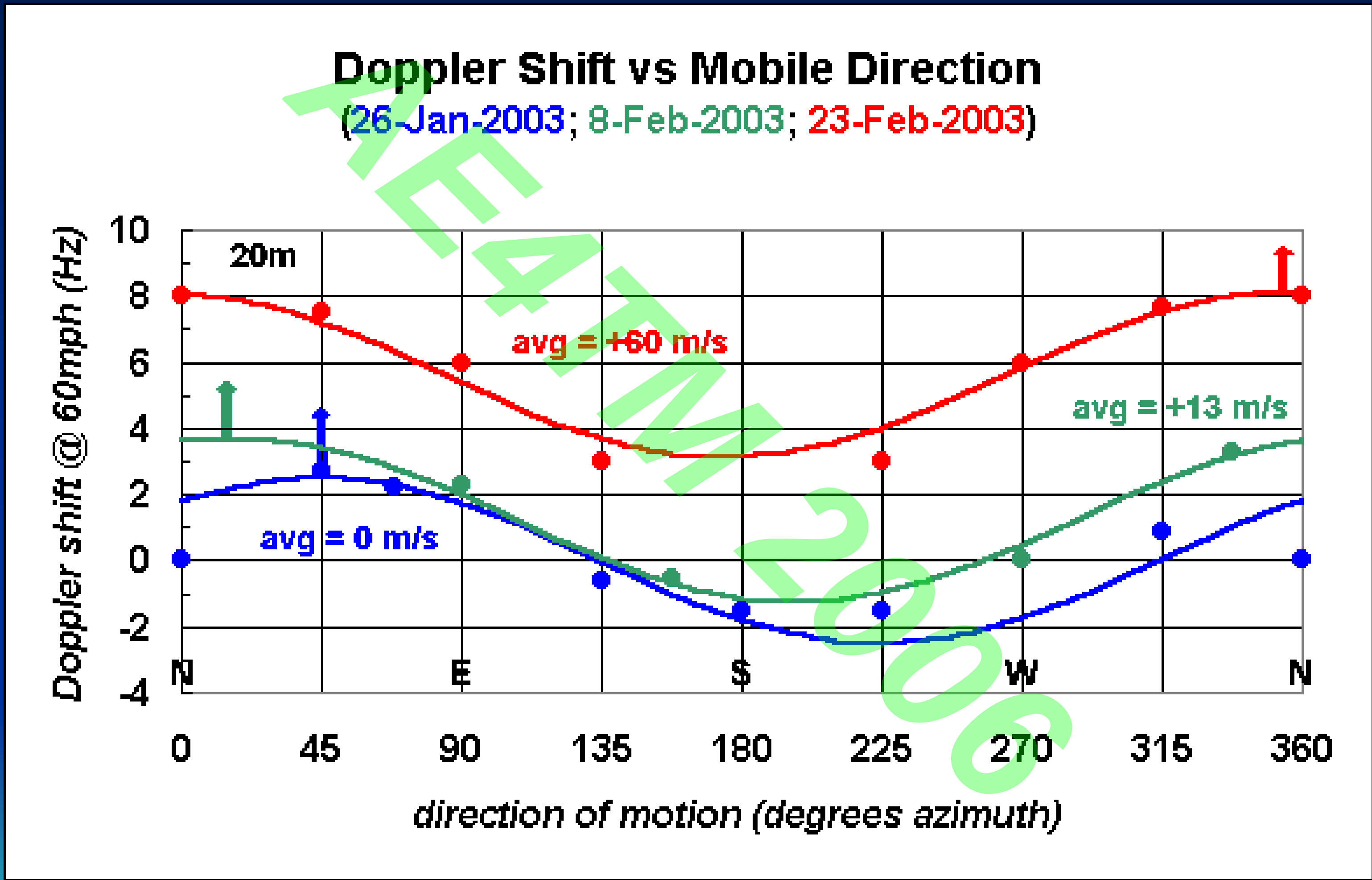


Backscatter Range vs Wavelength

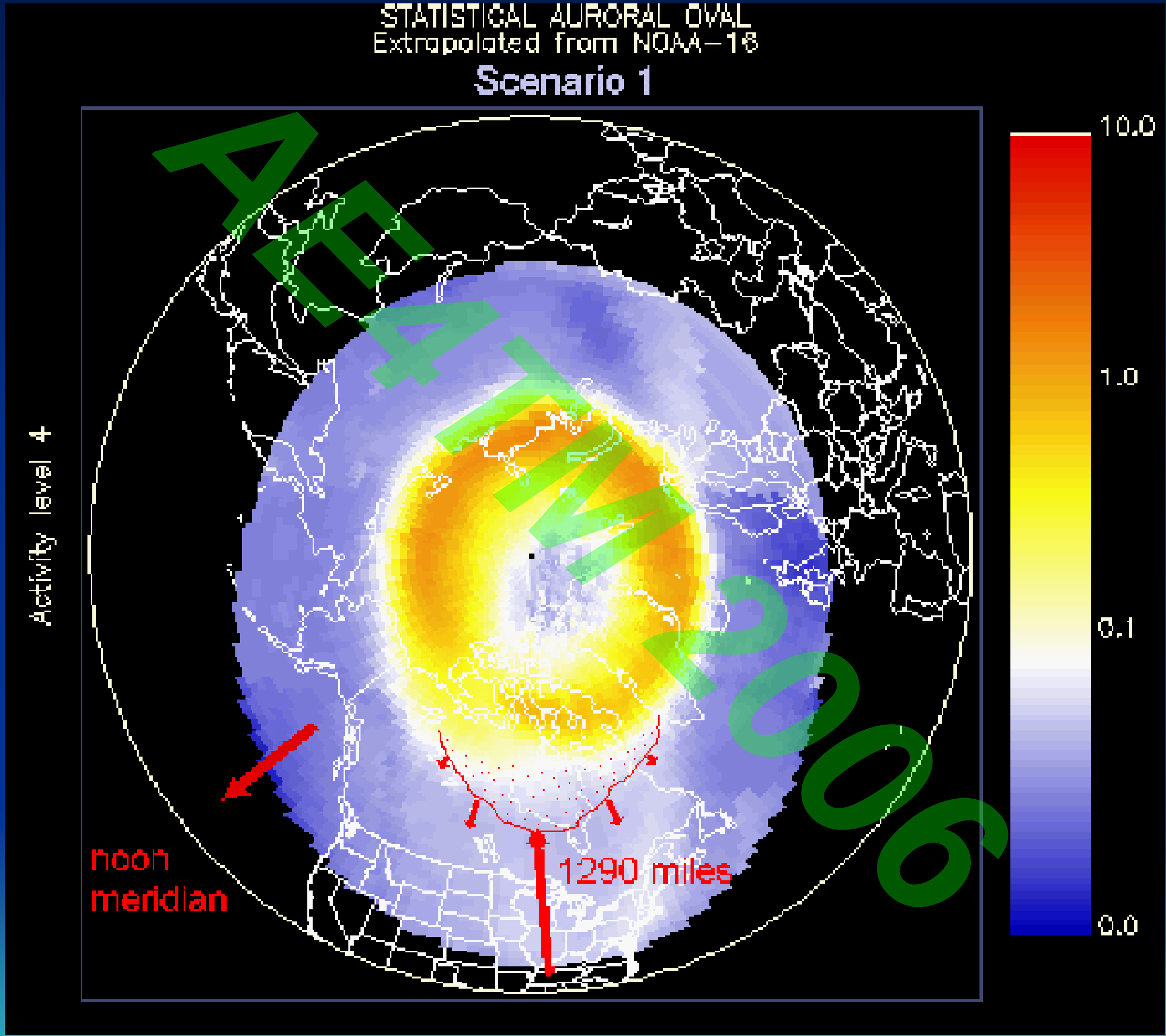


$N_{max} \sim 1.24 \times 10^{10} (f_o^2)\ m^{-3}$

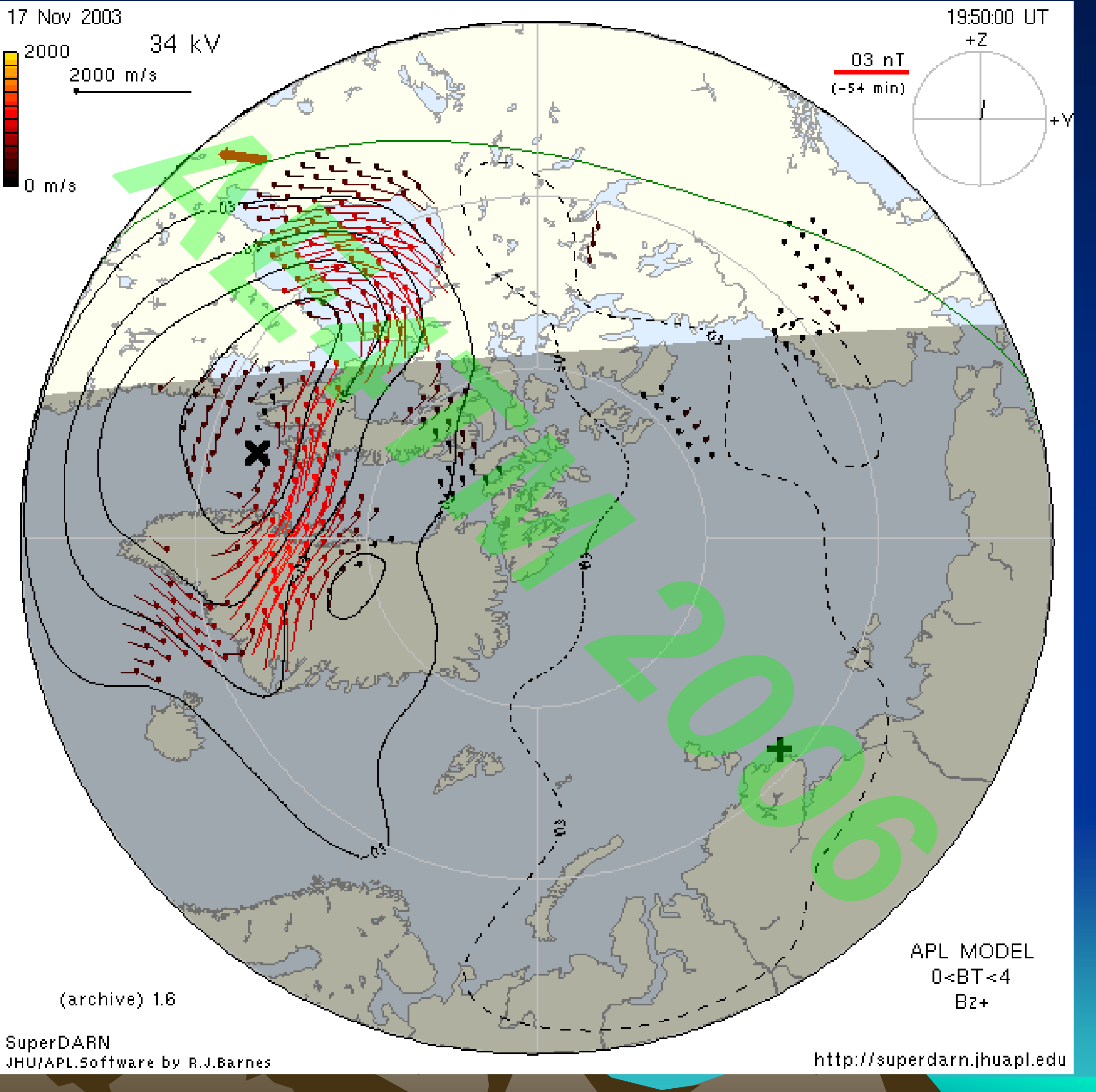
Direction to Backscatter Source



Auroral Oval and Backscatter



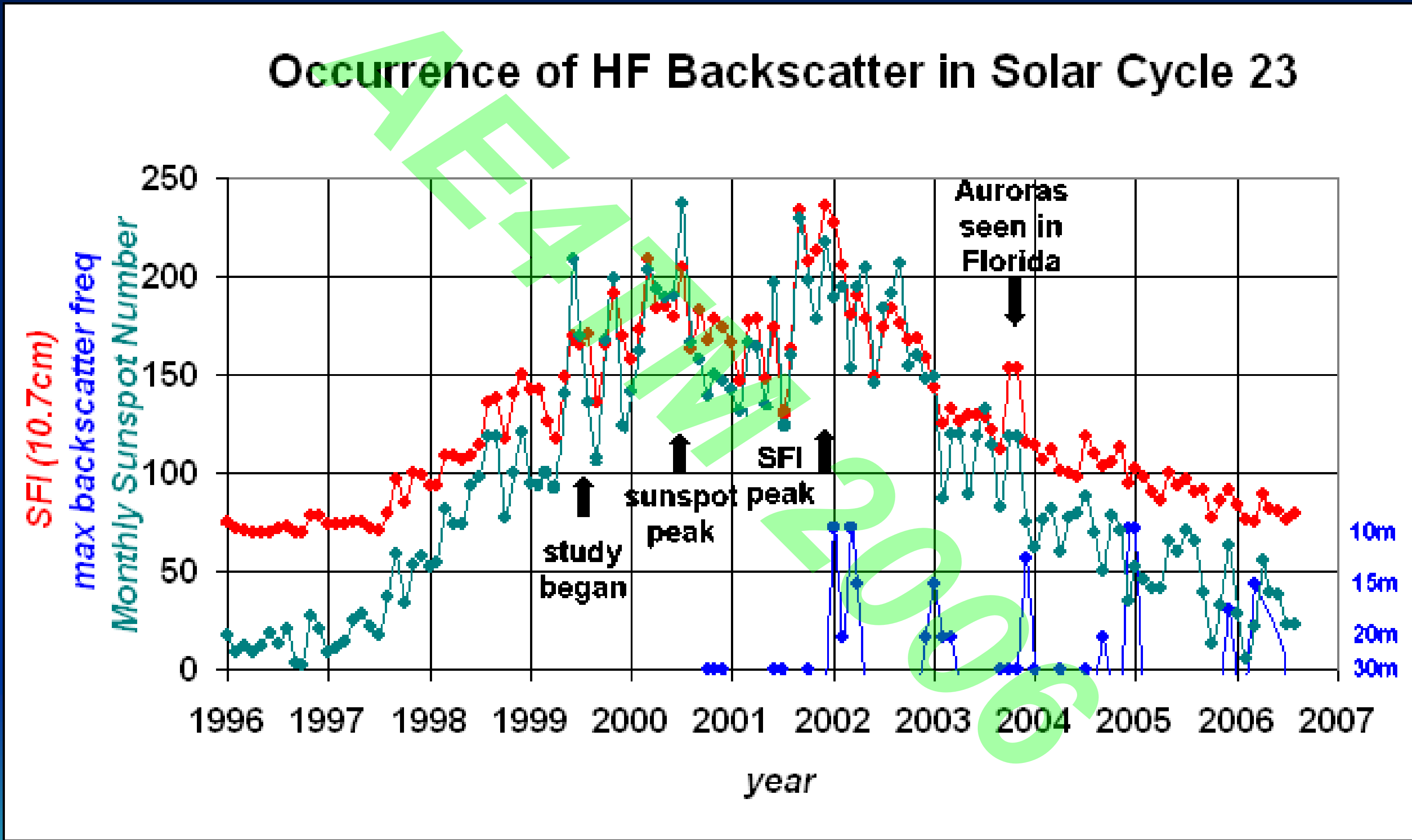
Source of Backscatter Ion Clouds



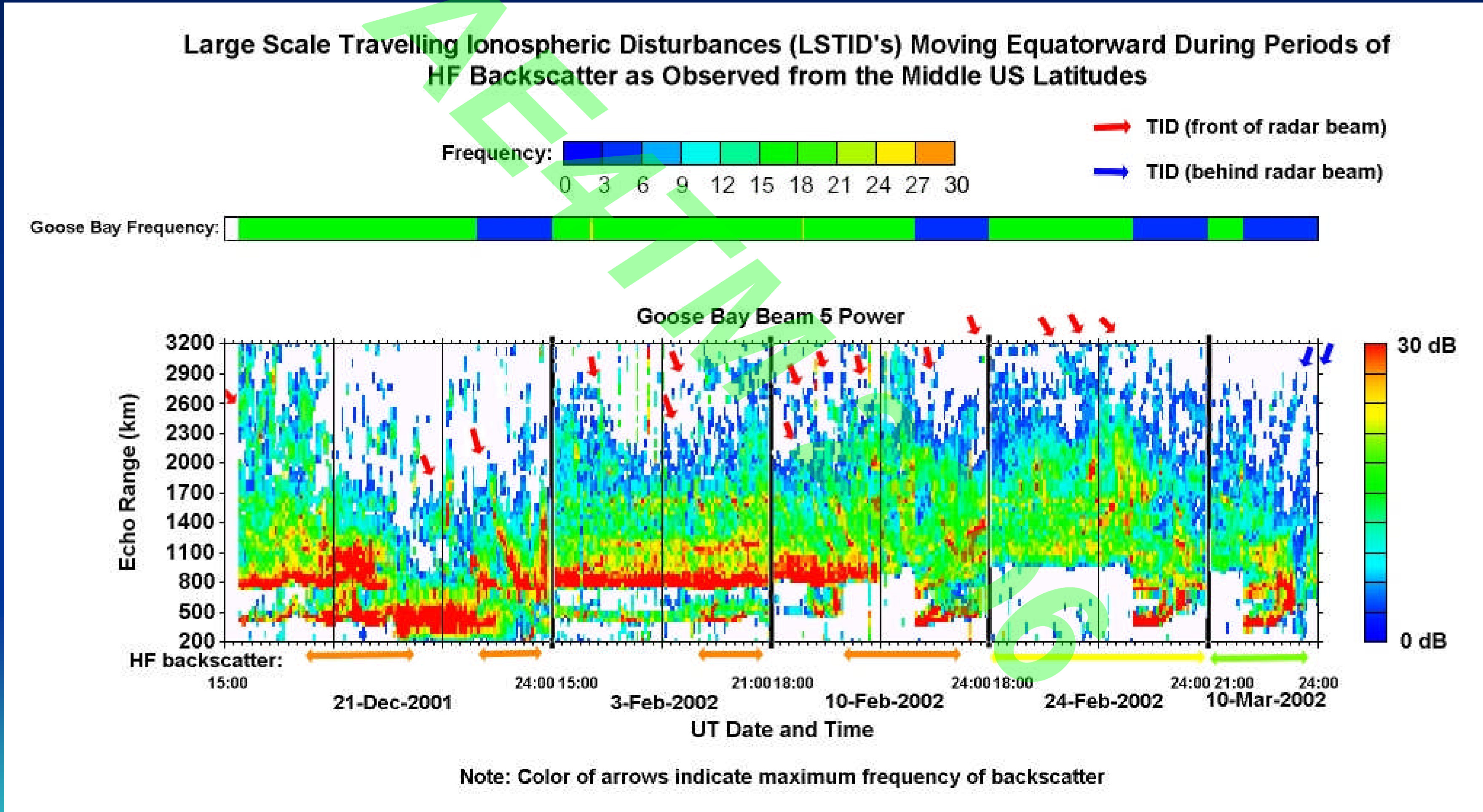
Animation: http://ecjones.org/_backscat/Nov17_2003_bksct.gif

Auroral Images (Fairbanks AK)

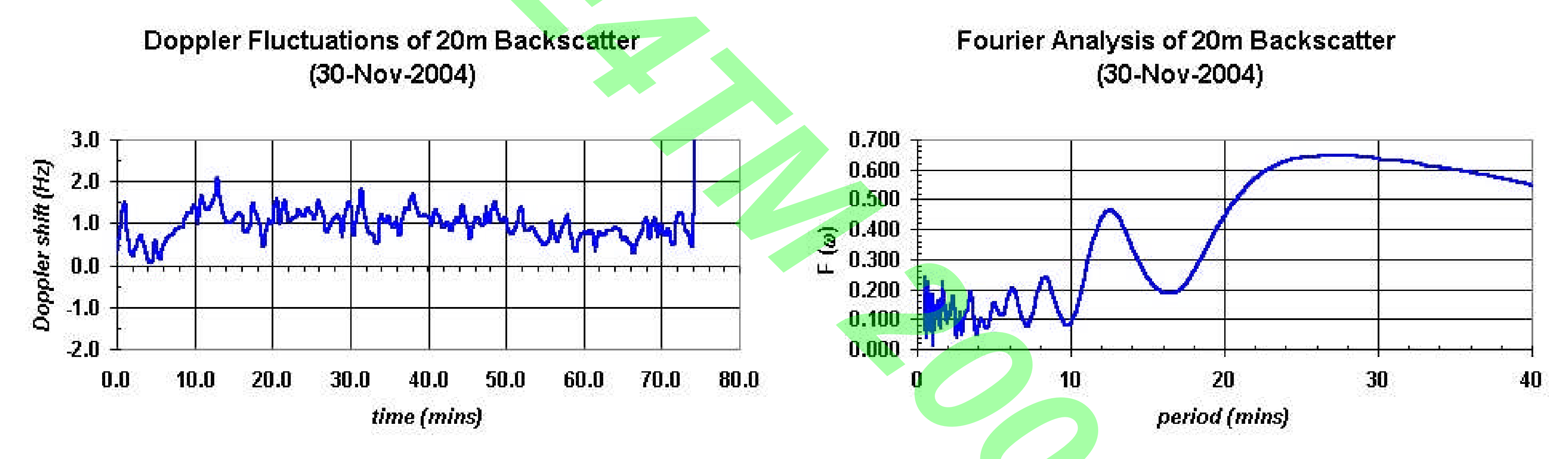
Seasonal Pattern for Backscatter



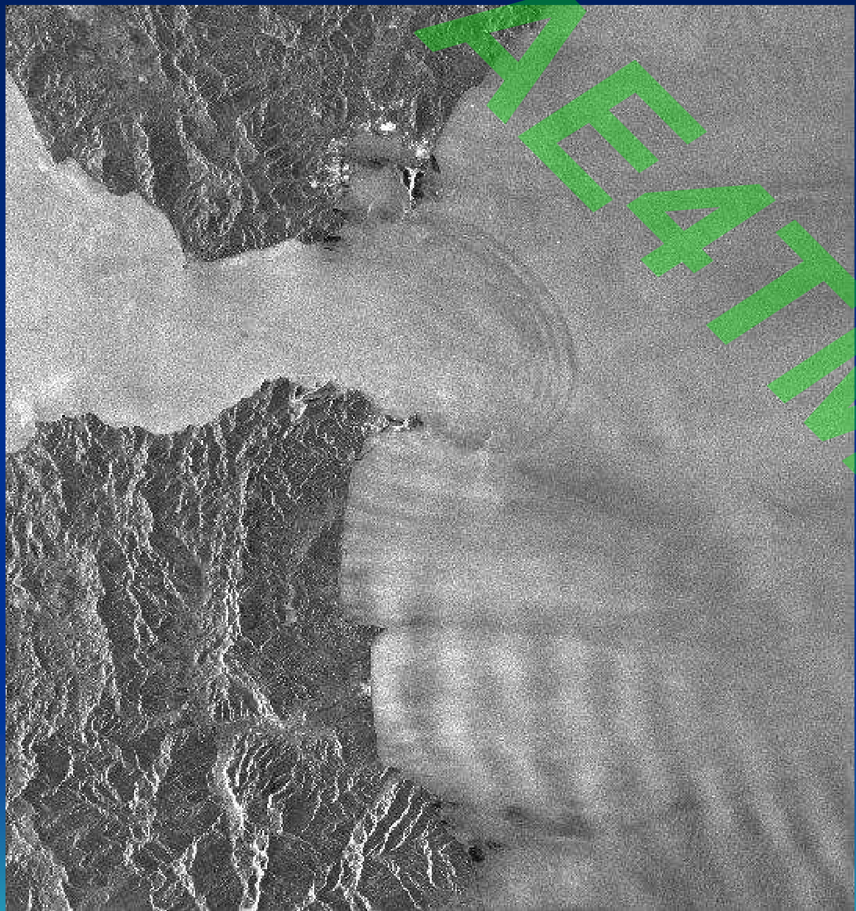
Backscatter with SuperDARN

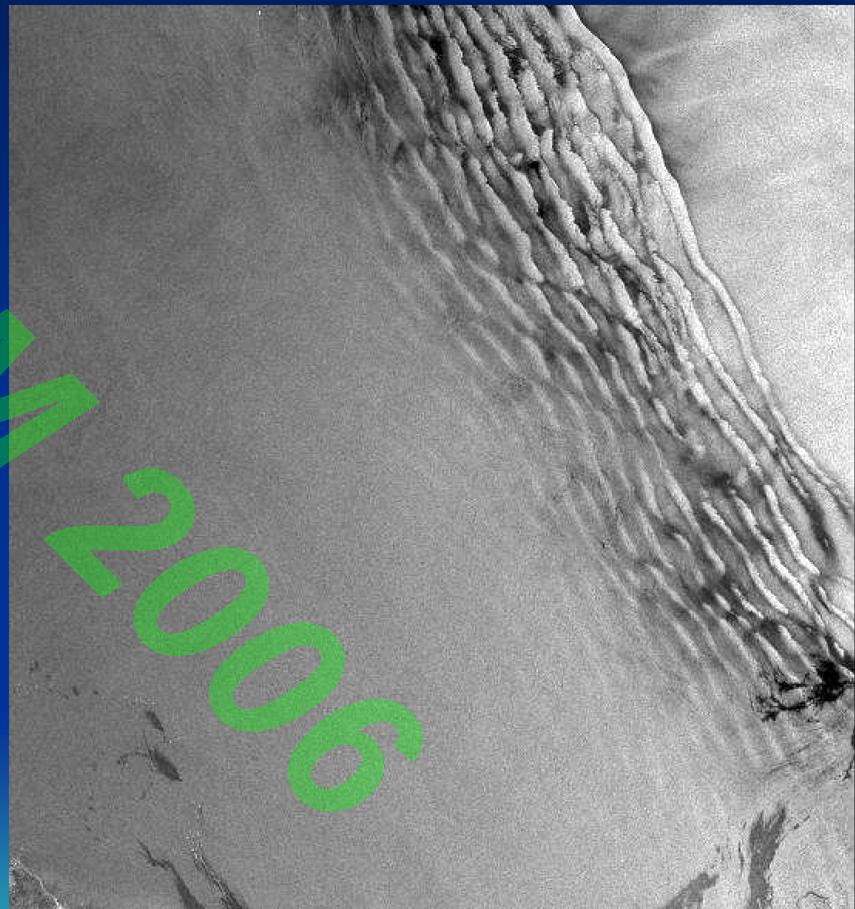


Backscatter and TID's
(Travelling Ionospheric Disturbances)



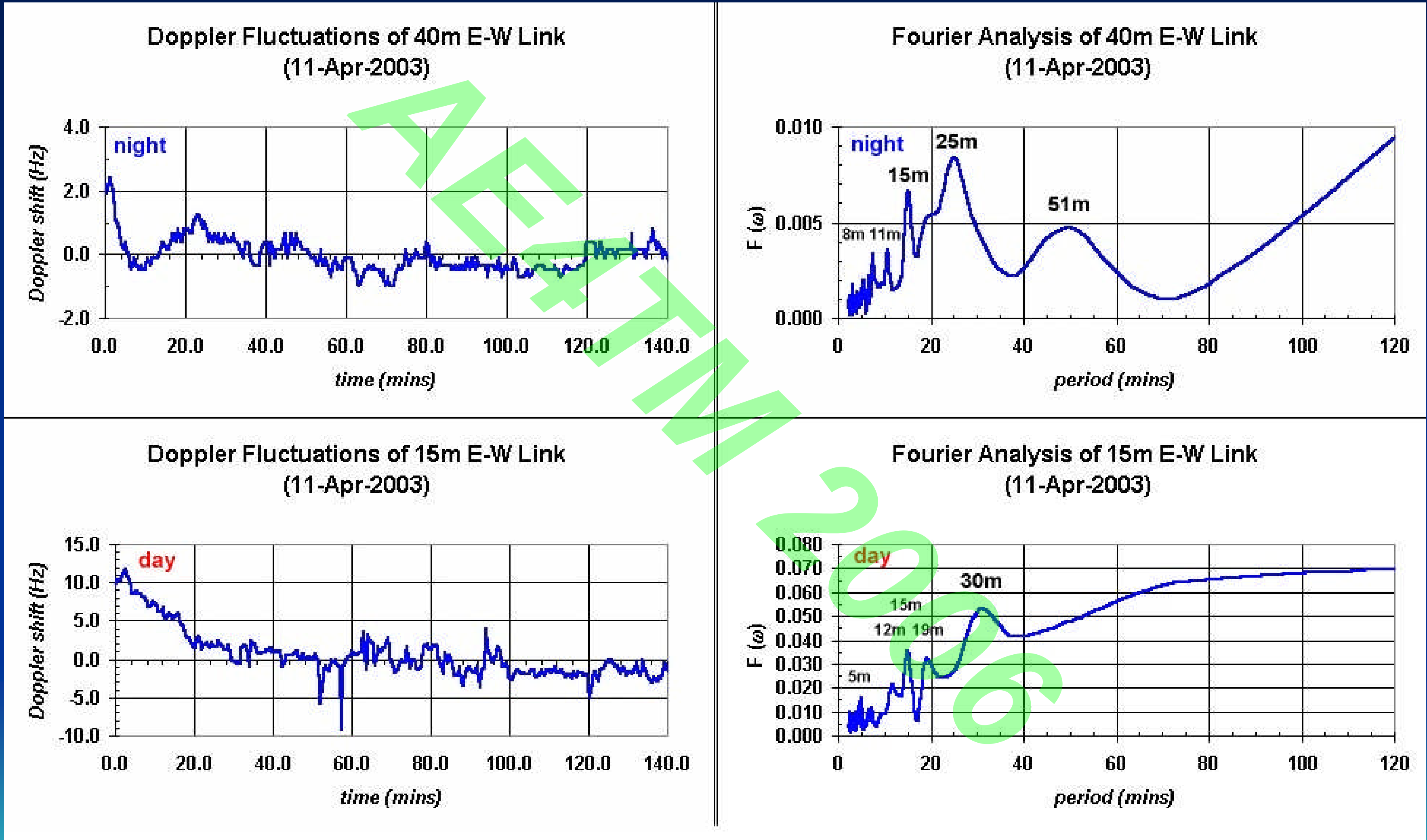
Atmospheric Gravity Waves (AGW)



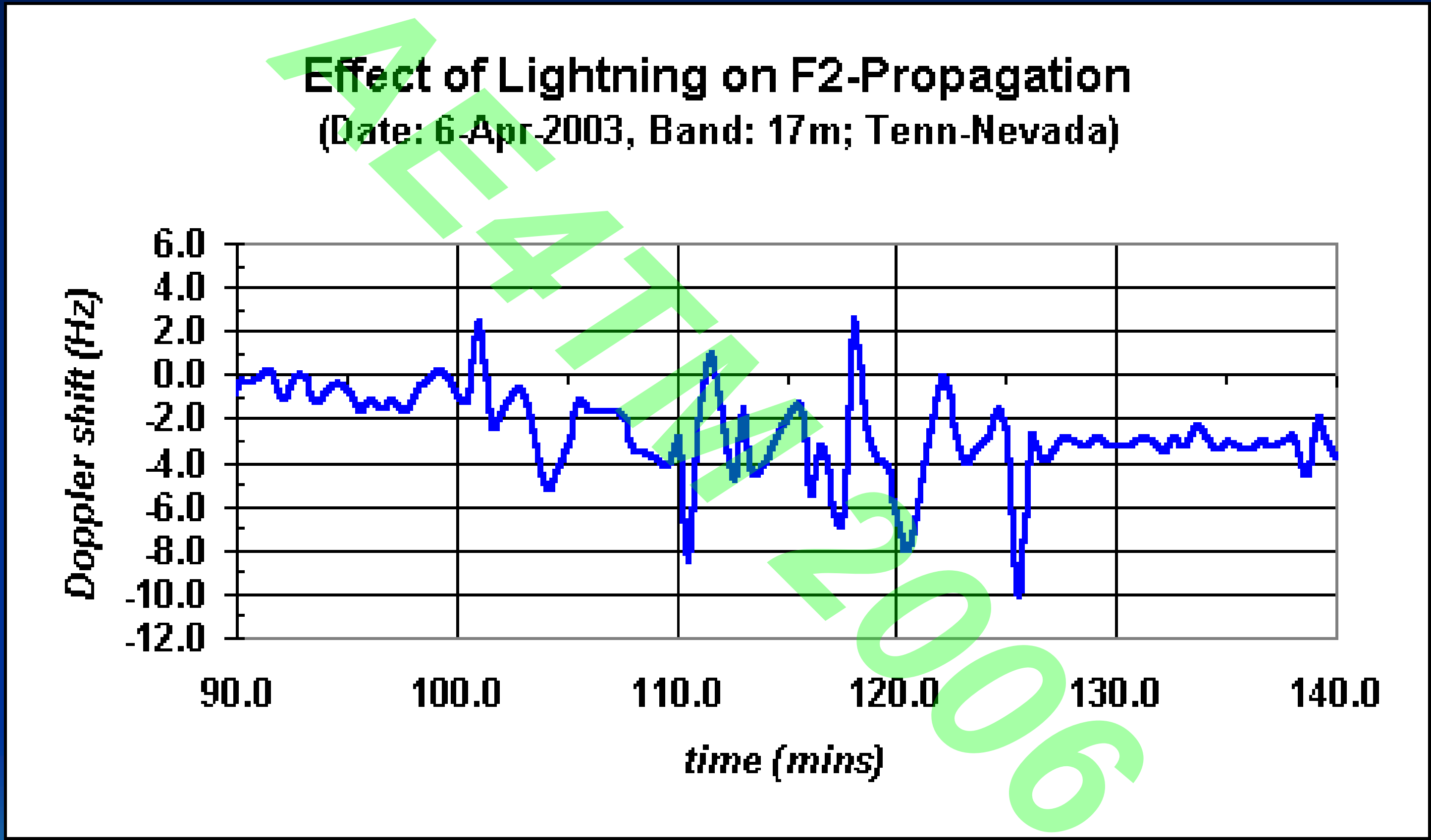


HF Doppler Study

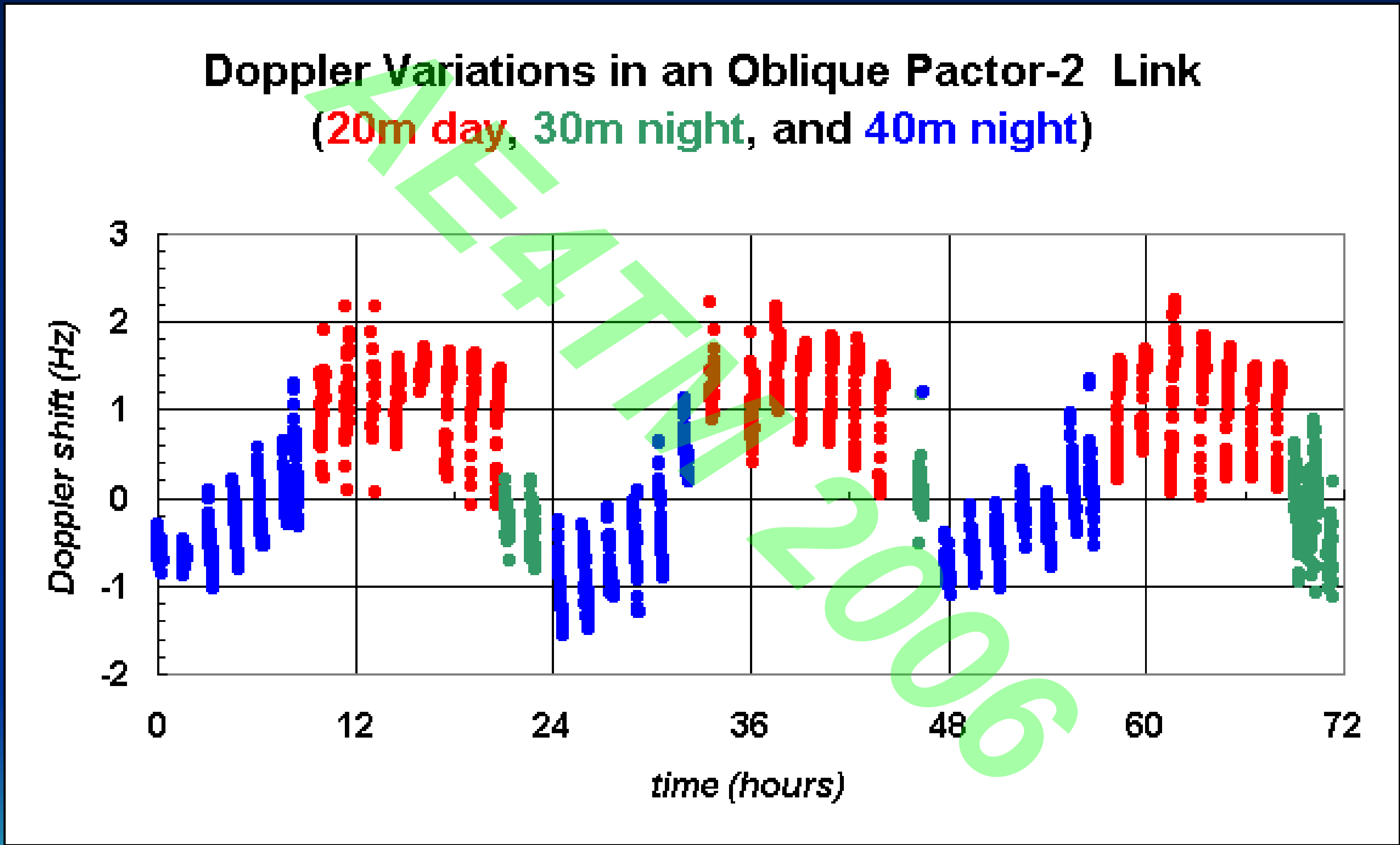
HF Doppler Fluctuations



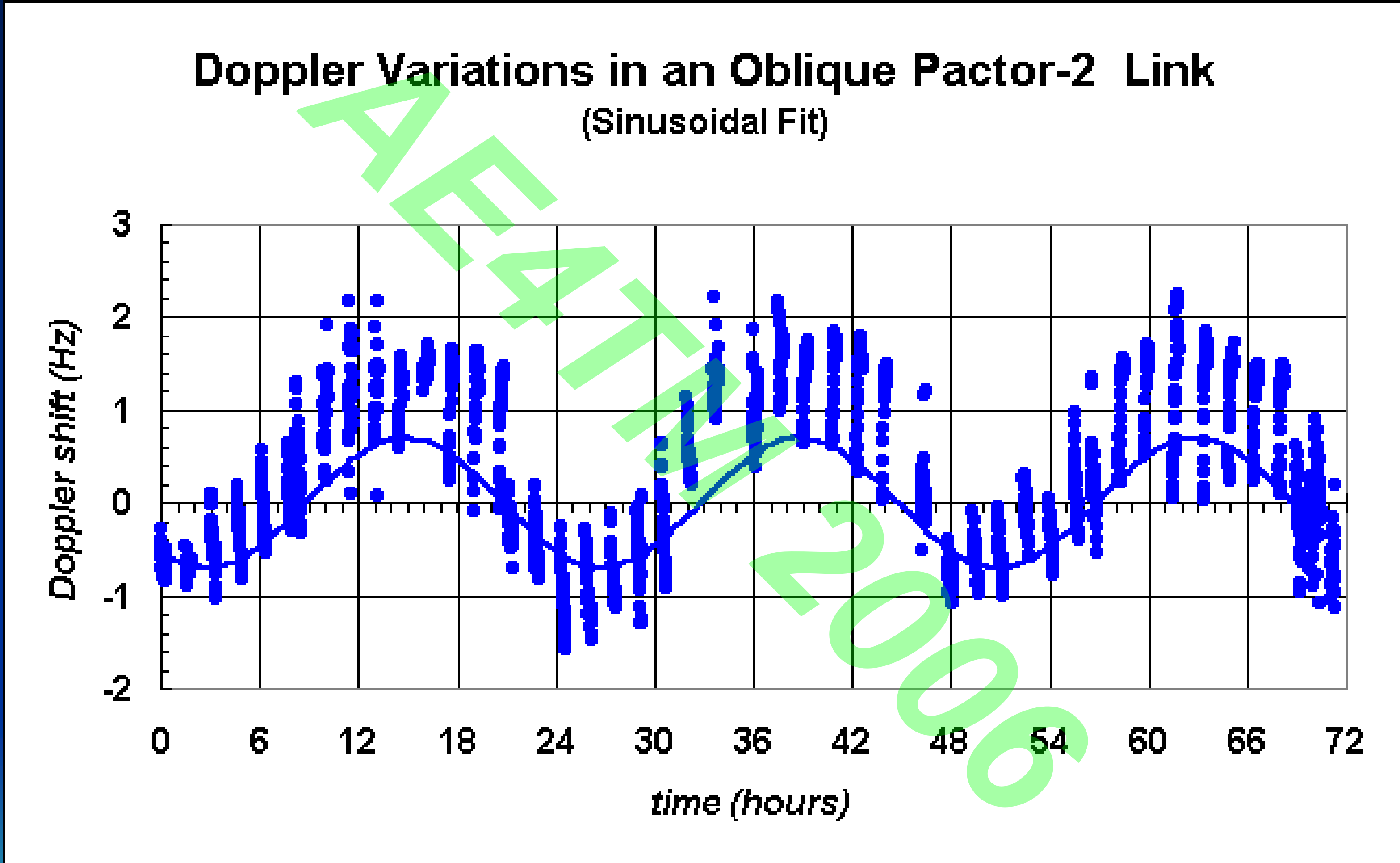
EMP Impulses from Lightning



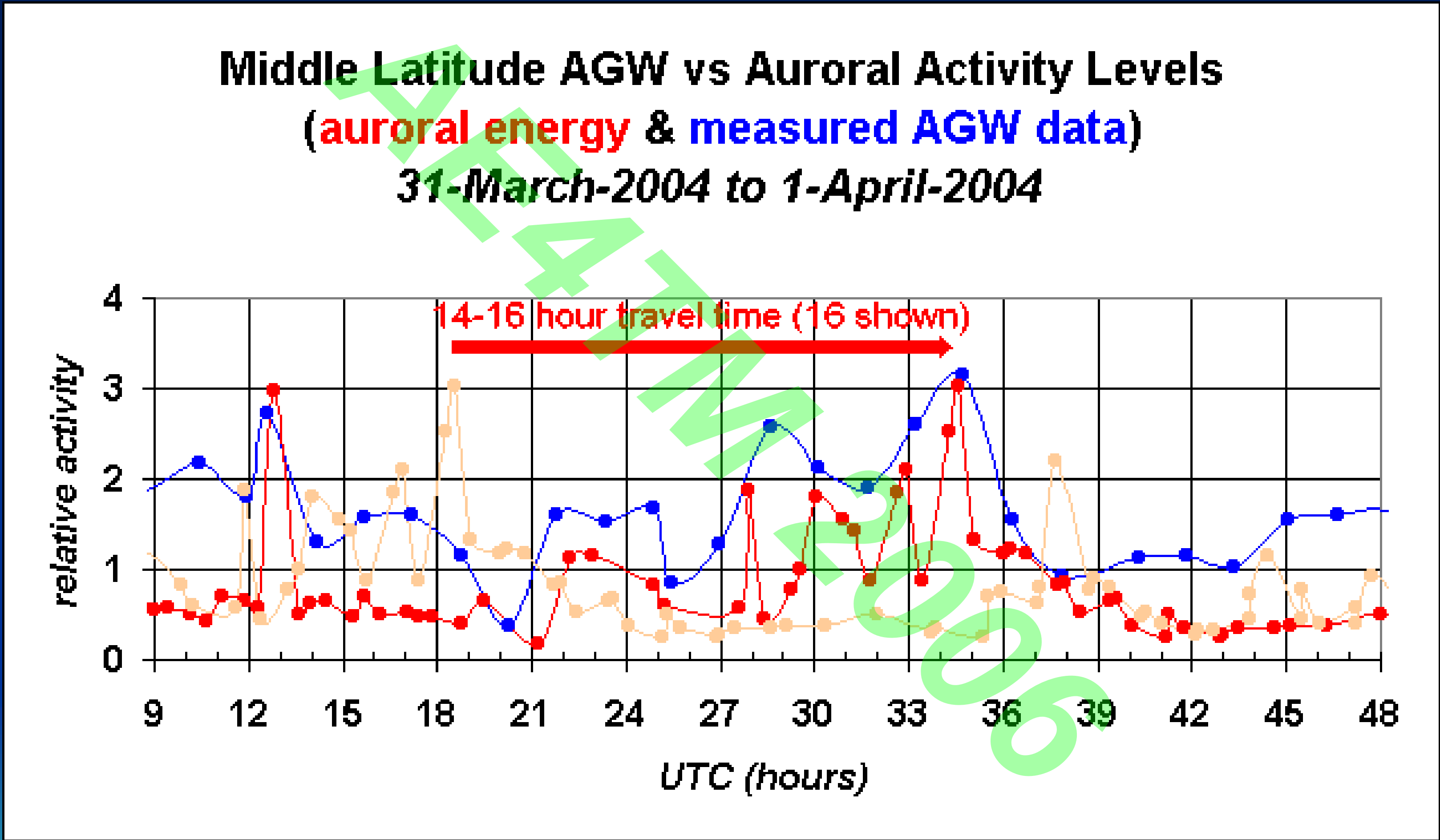
Doppler Shifts in Oblique Links



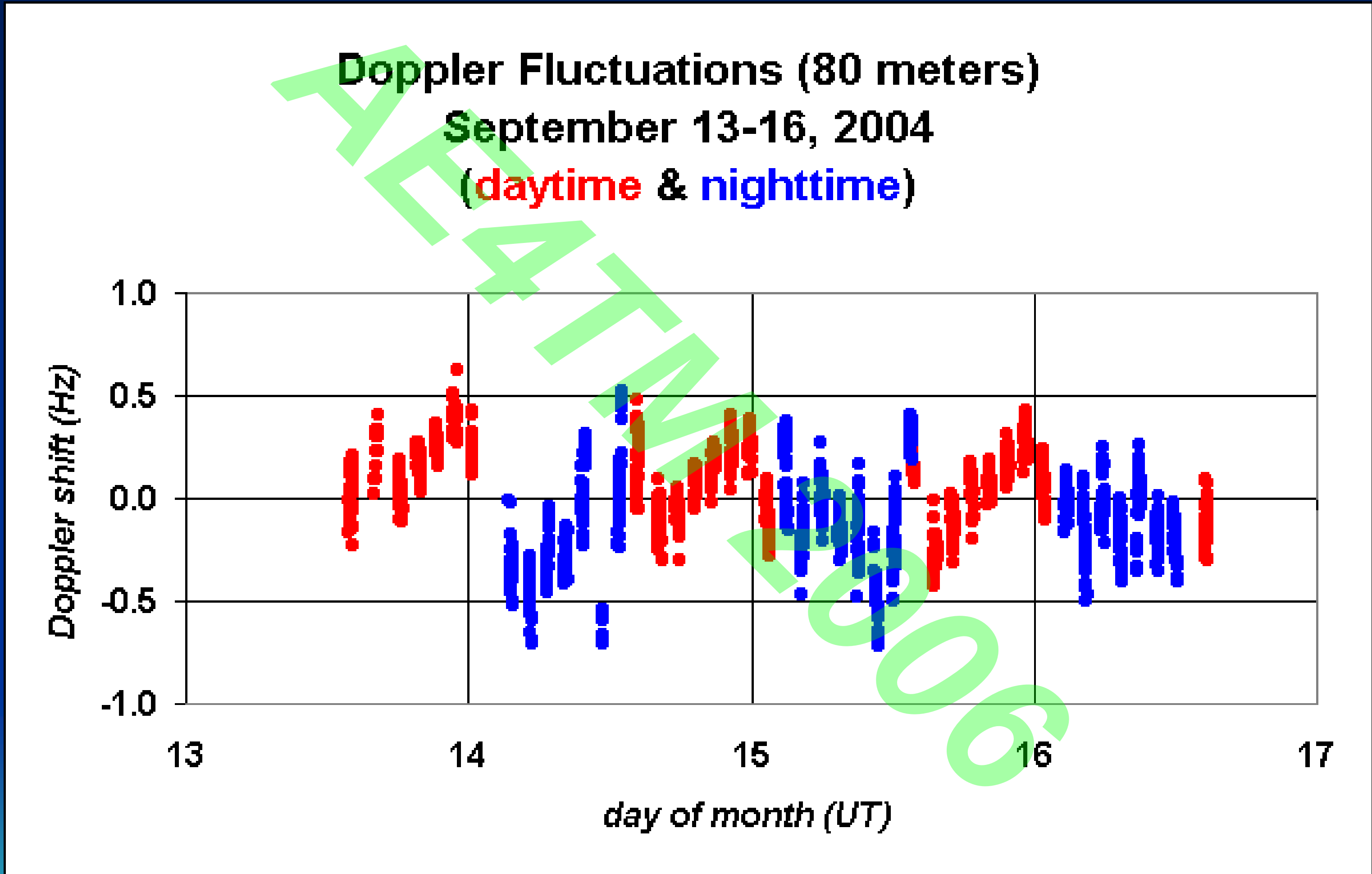
Determining the 0 Hz Doppler Shift



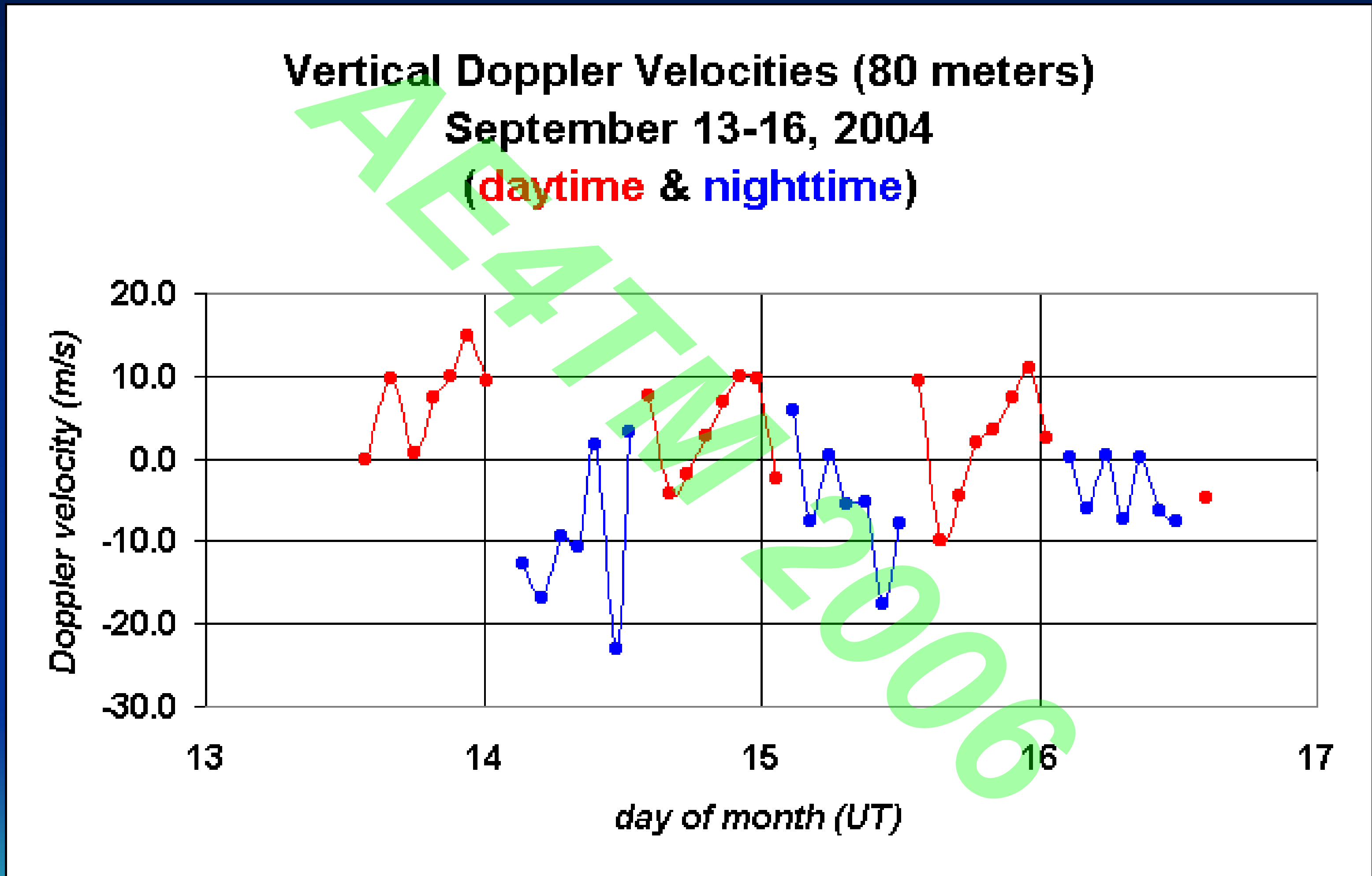
Determining the TID Velocity



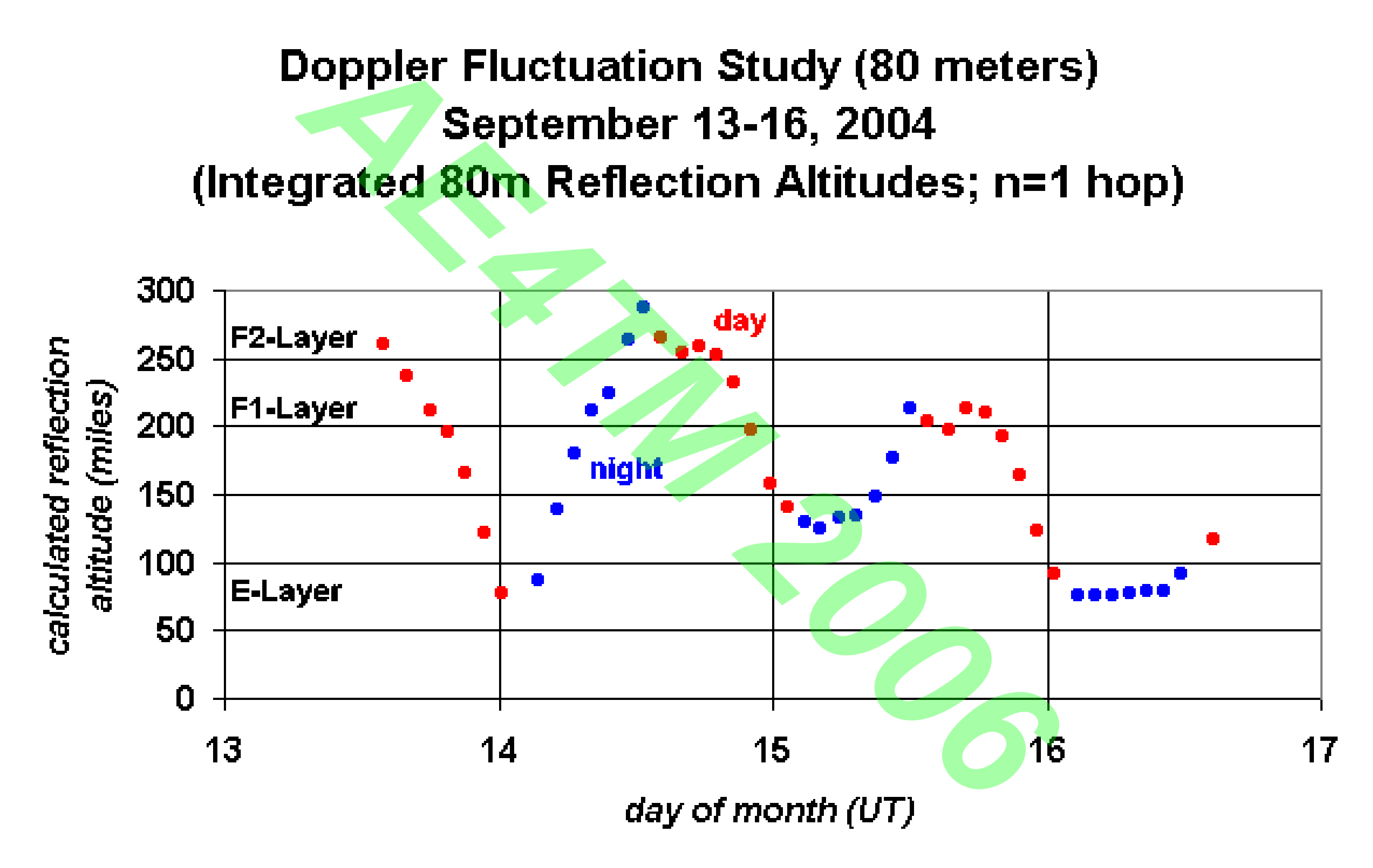
Doppler Shifts on 80m



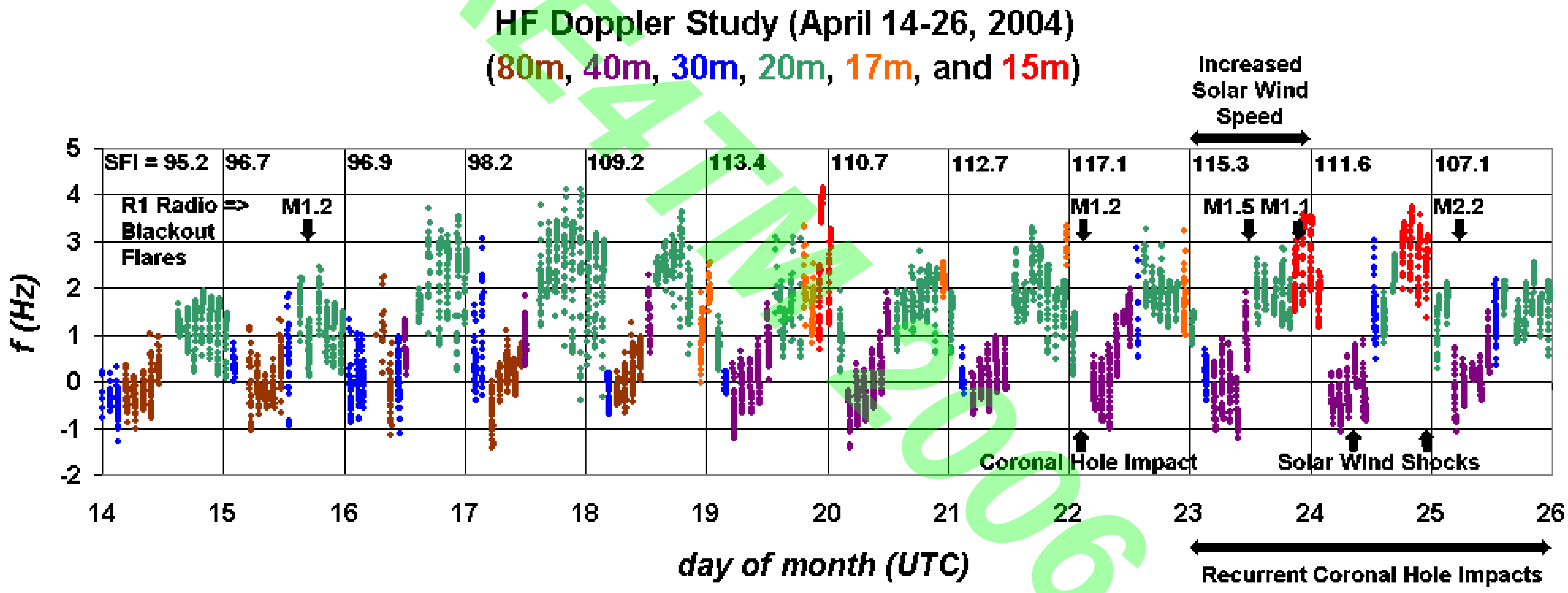
Calculated Vertical Velocities on 80m



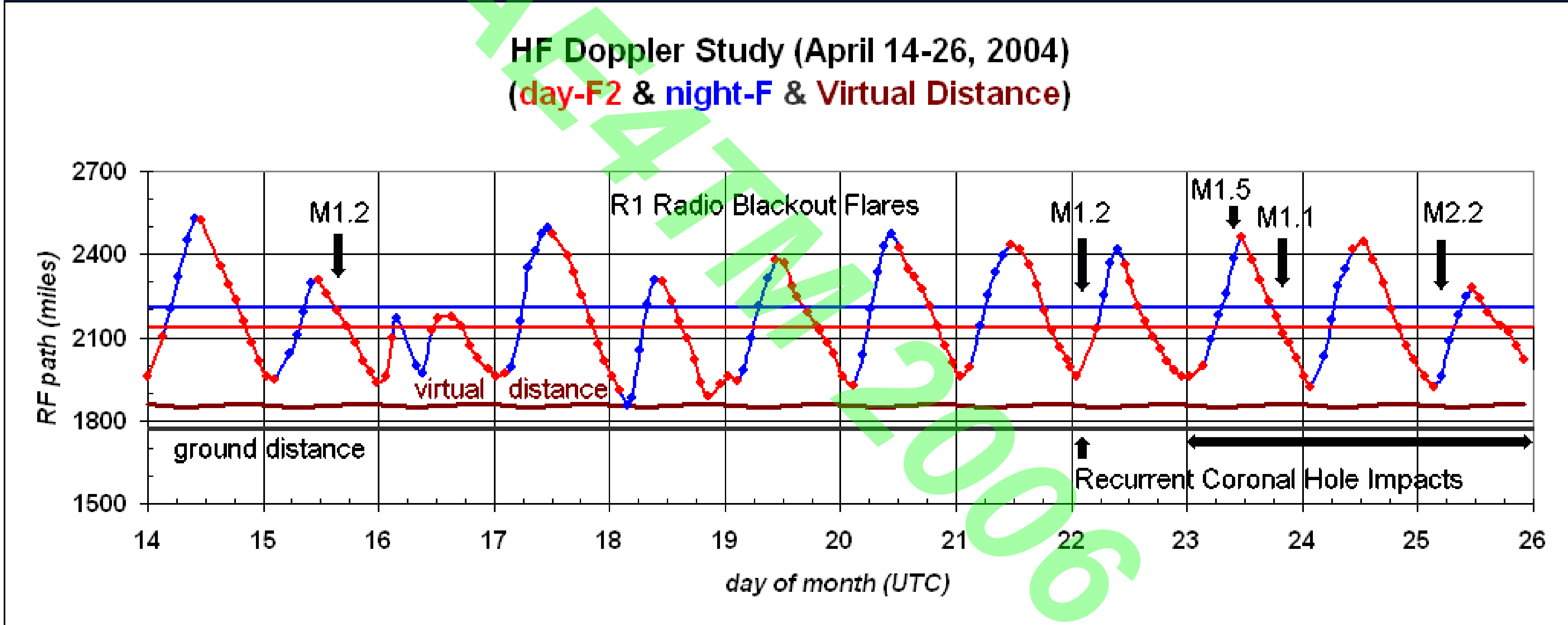
Integrated Reflection Altitudes on 80m



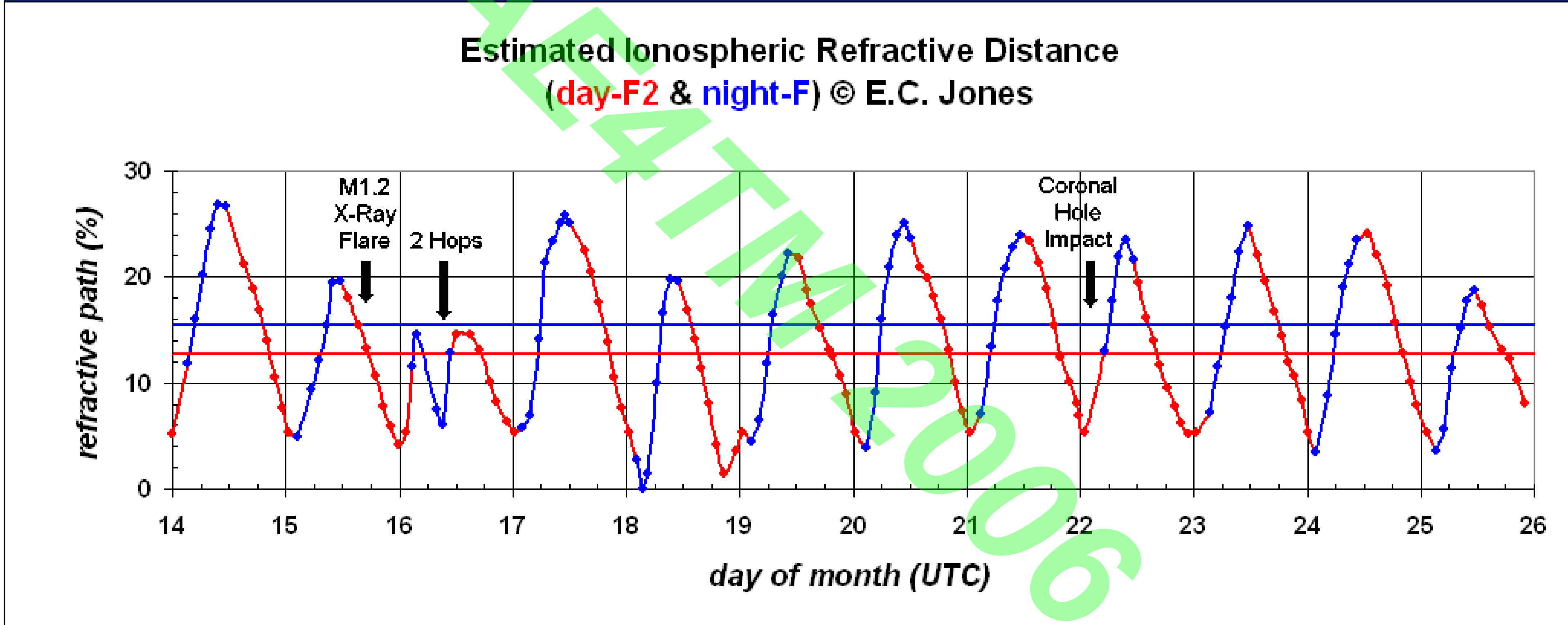
Doppler Shift Variation over a 12 Day Period (April 14-26, 2004)



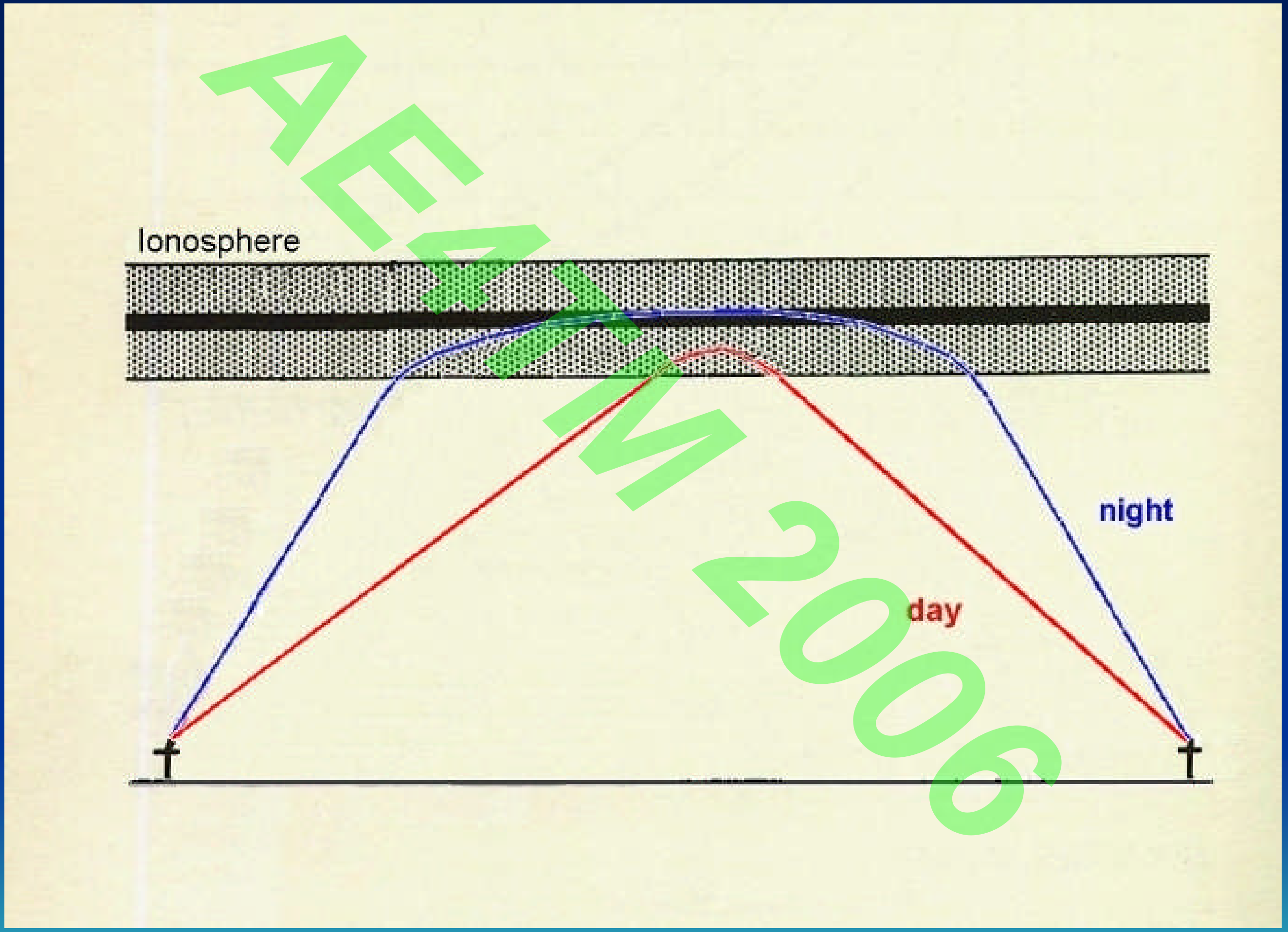
Integrated RF Paths over a 12 Day Period (April 14-26, 2004)



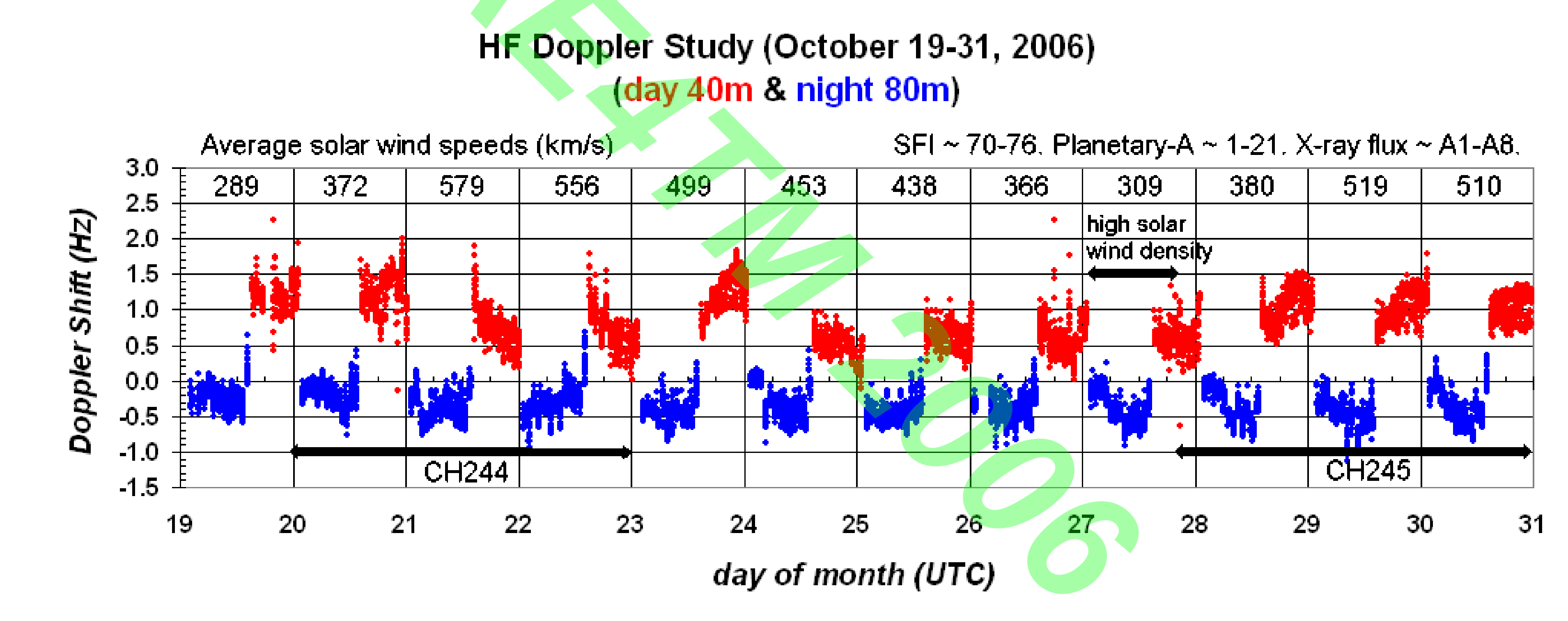
Ionosphere Refraction Distance (April 14-26, 2004)



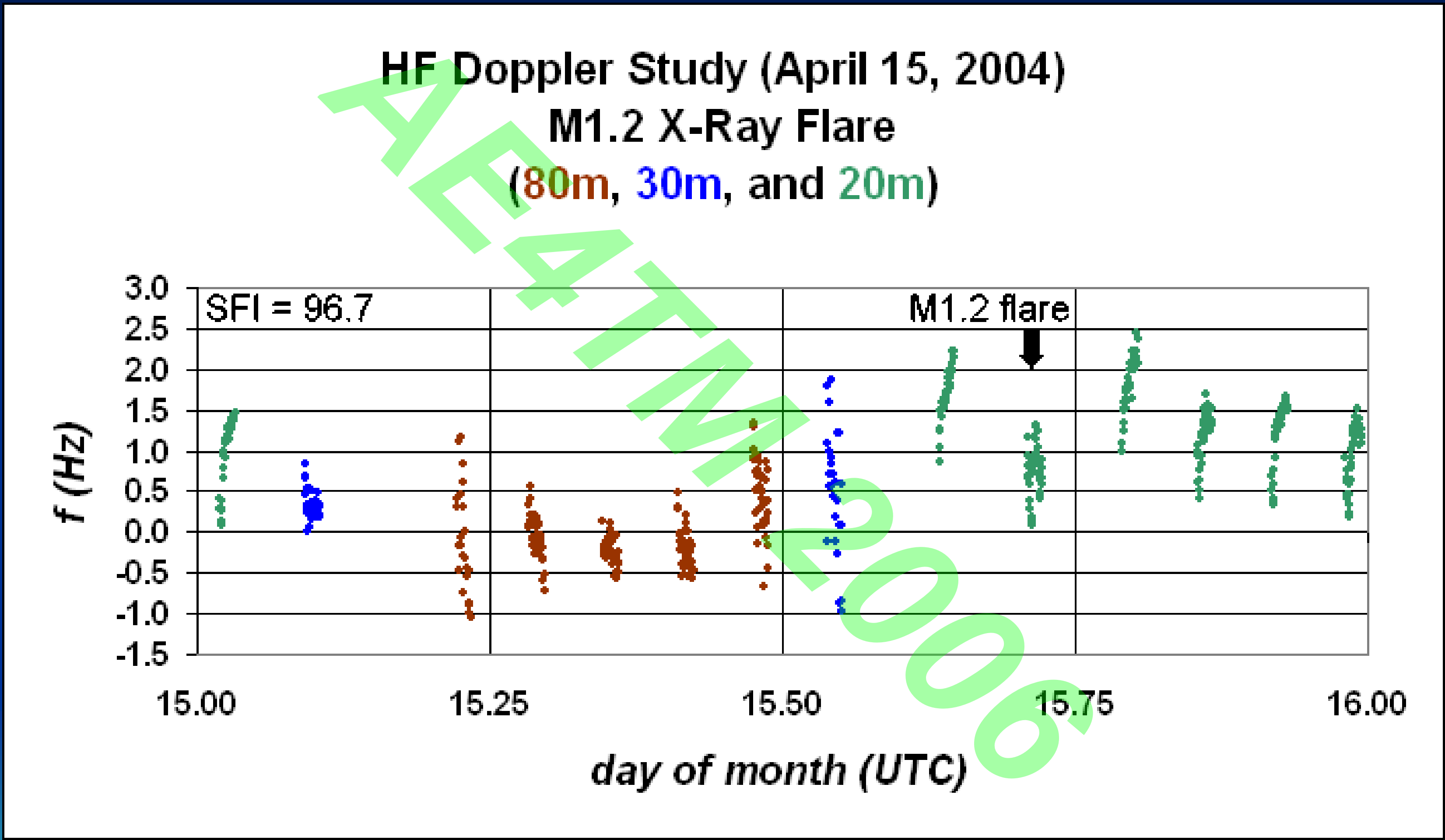
HF Ionospheric Refraction



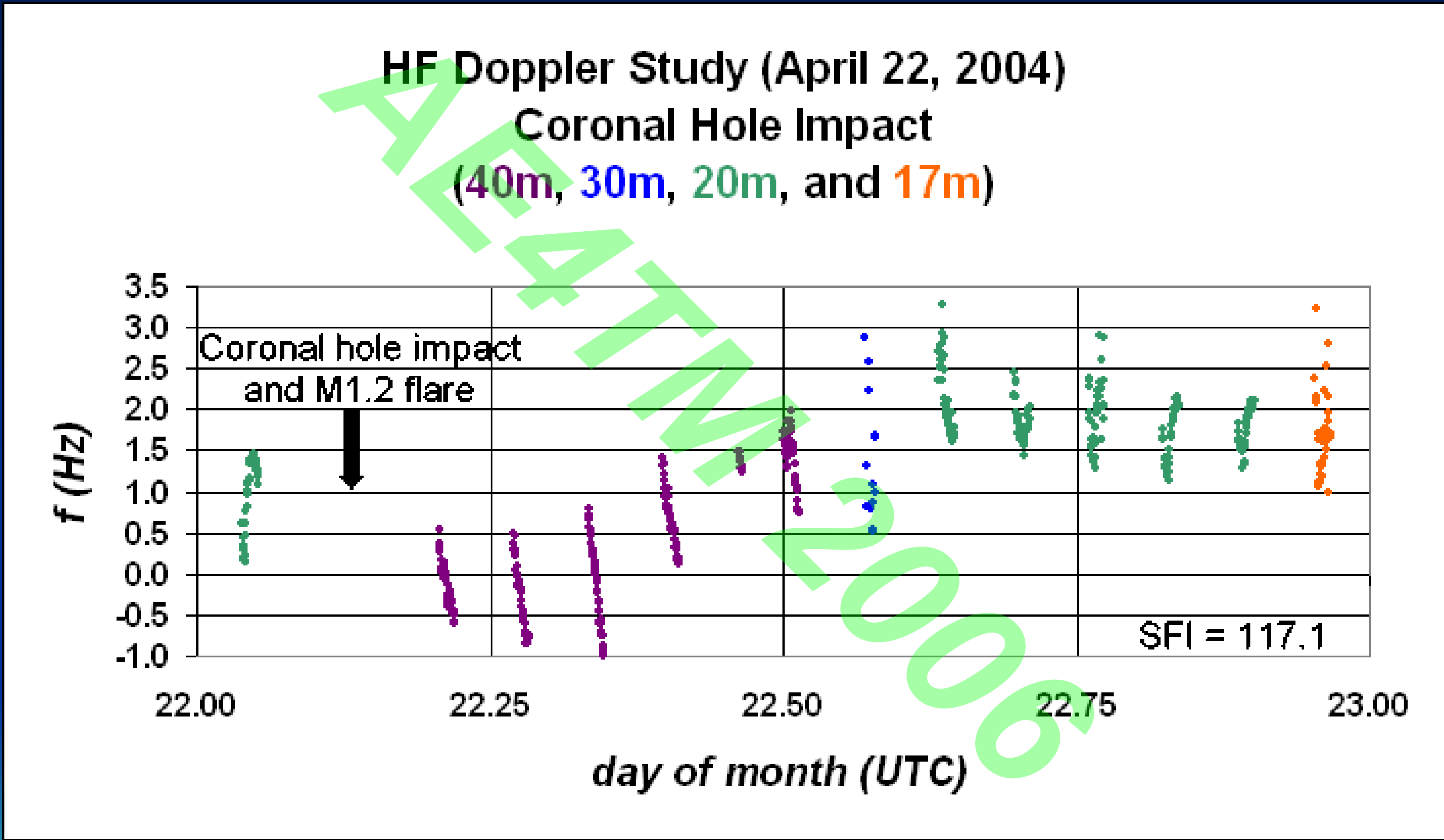
Doppler Shift Variation over a 12 Day Period (October 19-31, 2006)



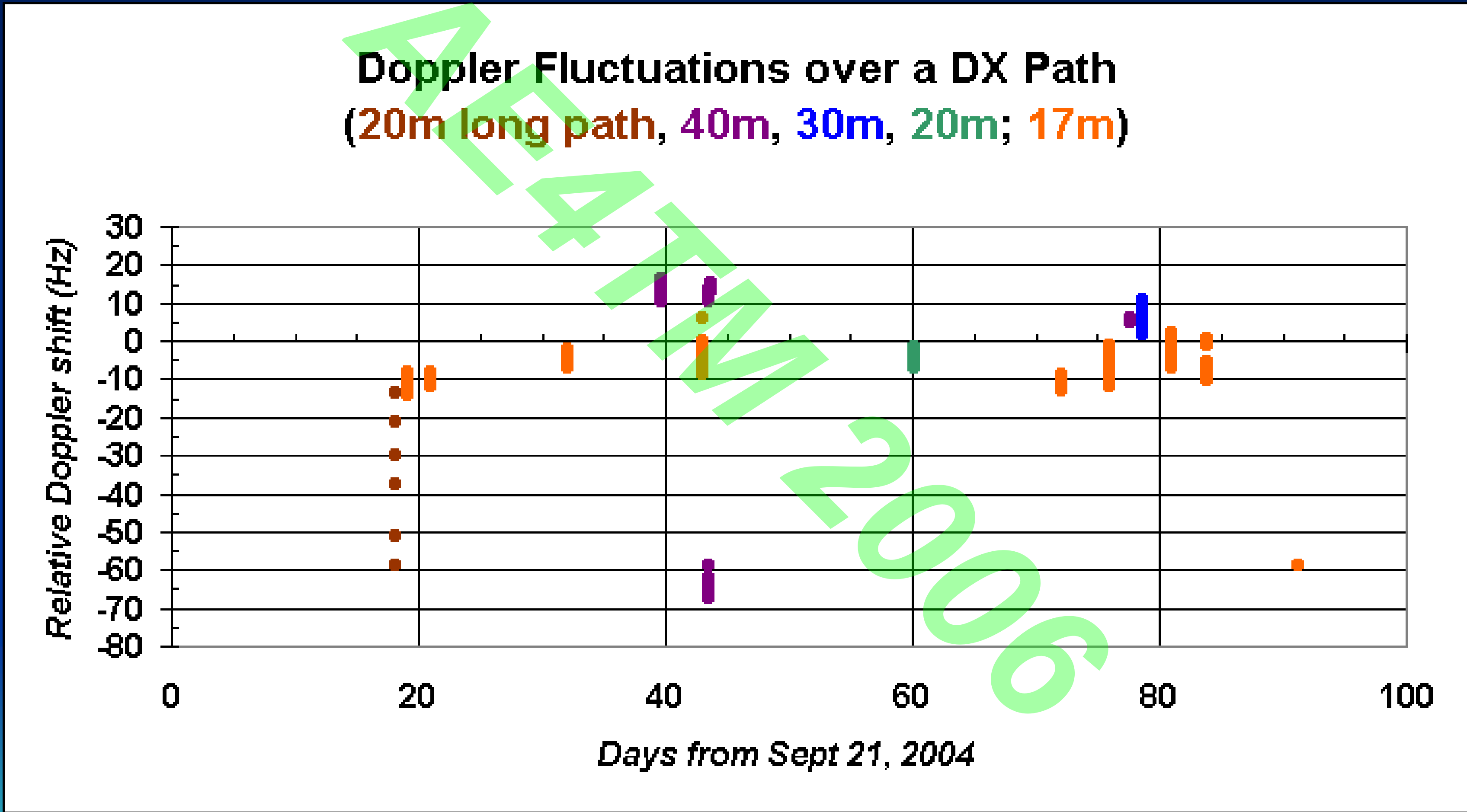
HF Effect from X-Ray Flare



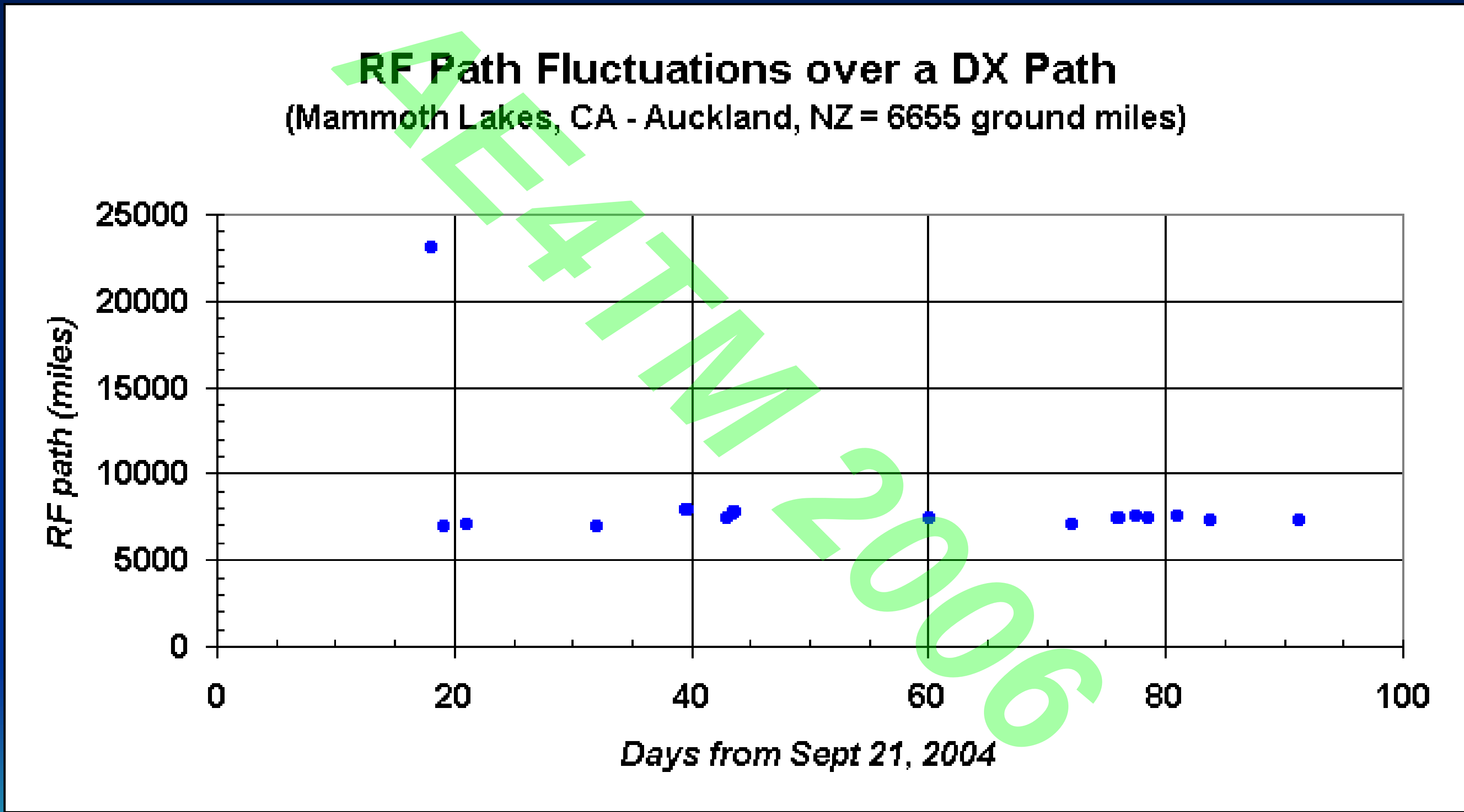
HF Effect from Coronal Hole Impact



Doppler Shifts over a DX Path



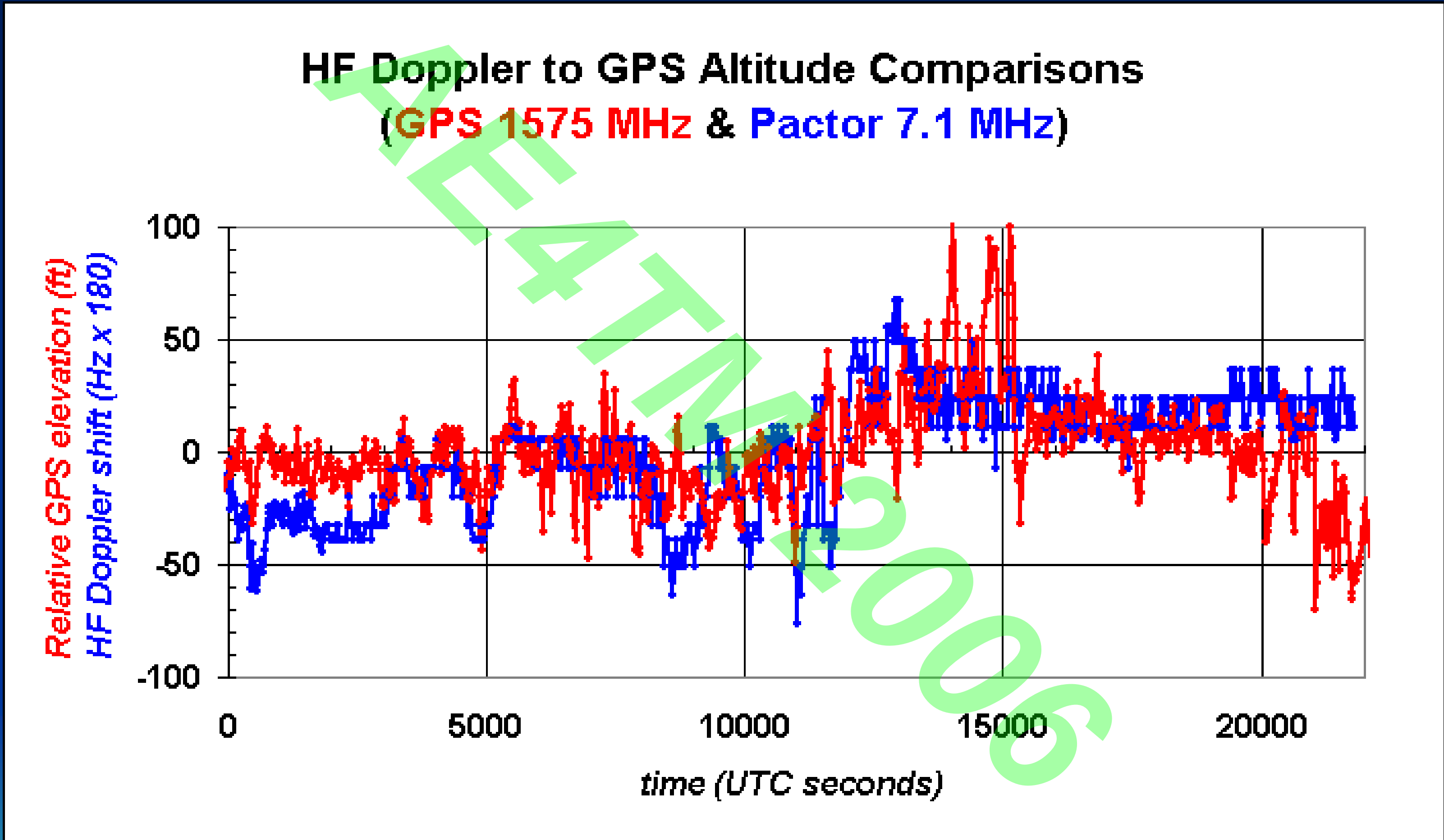
Propagation Distance over a DX Path



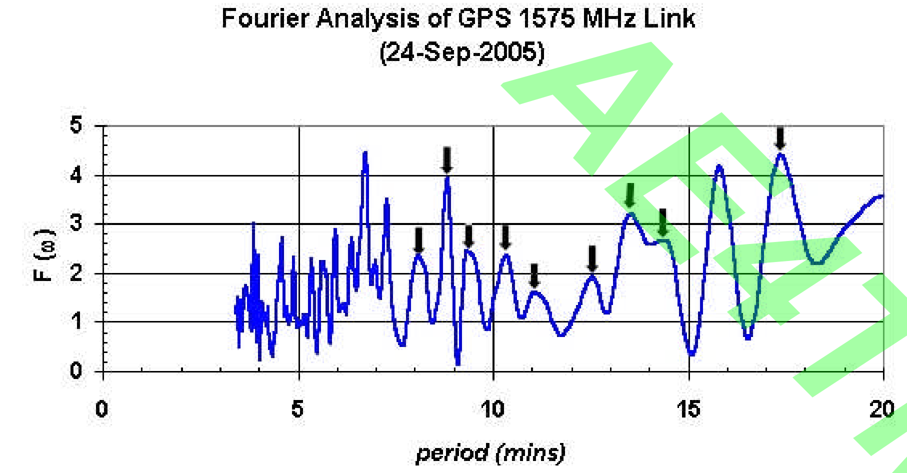
GPS Error Sources

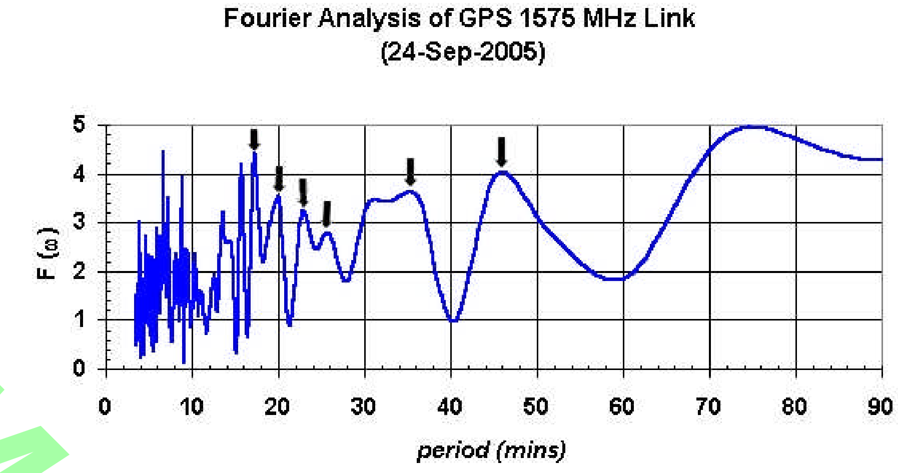
Error source	Potential error	Typical error
Ionosphere	5.0m	0.4m
Troposphere	0.5m	0.2m
Ephemeris data	2.5m	0m
Satellite clock drift	1.5m	0m
Multipath	0.6m	0.6m
Measurement noise	0.3m	0.3m
Total	~15m	~10m

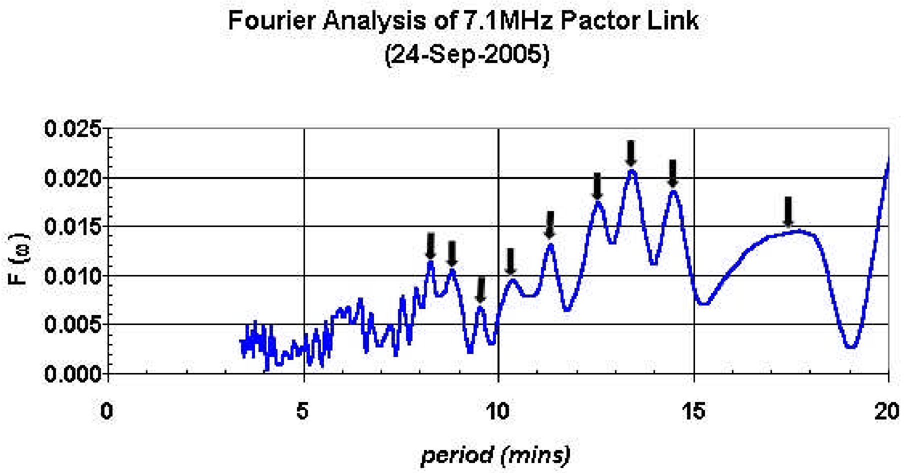
Application: Improving GPS Accuracy

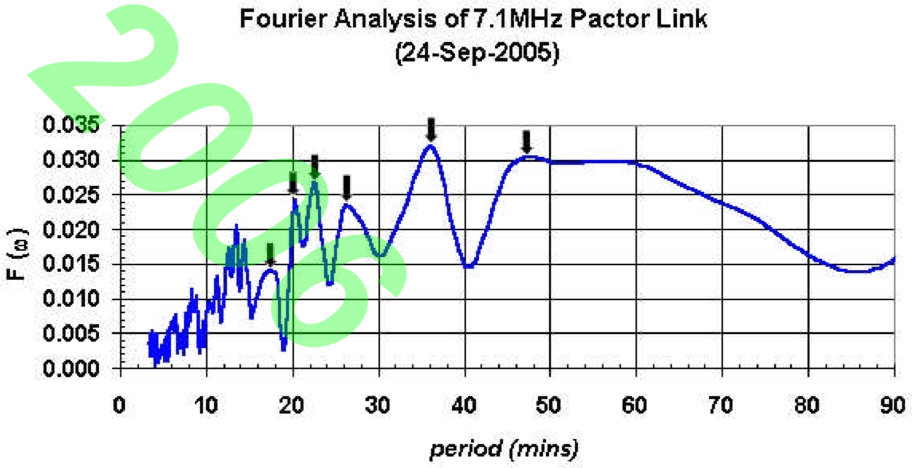


Fourier Analysis Comparisons

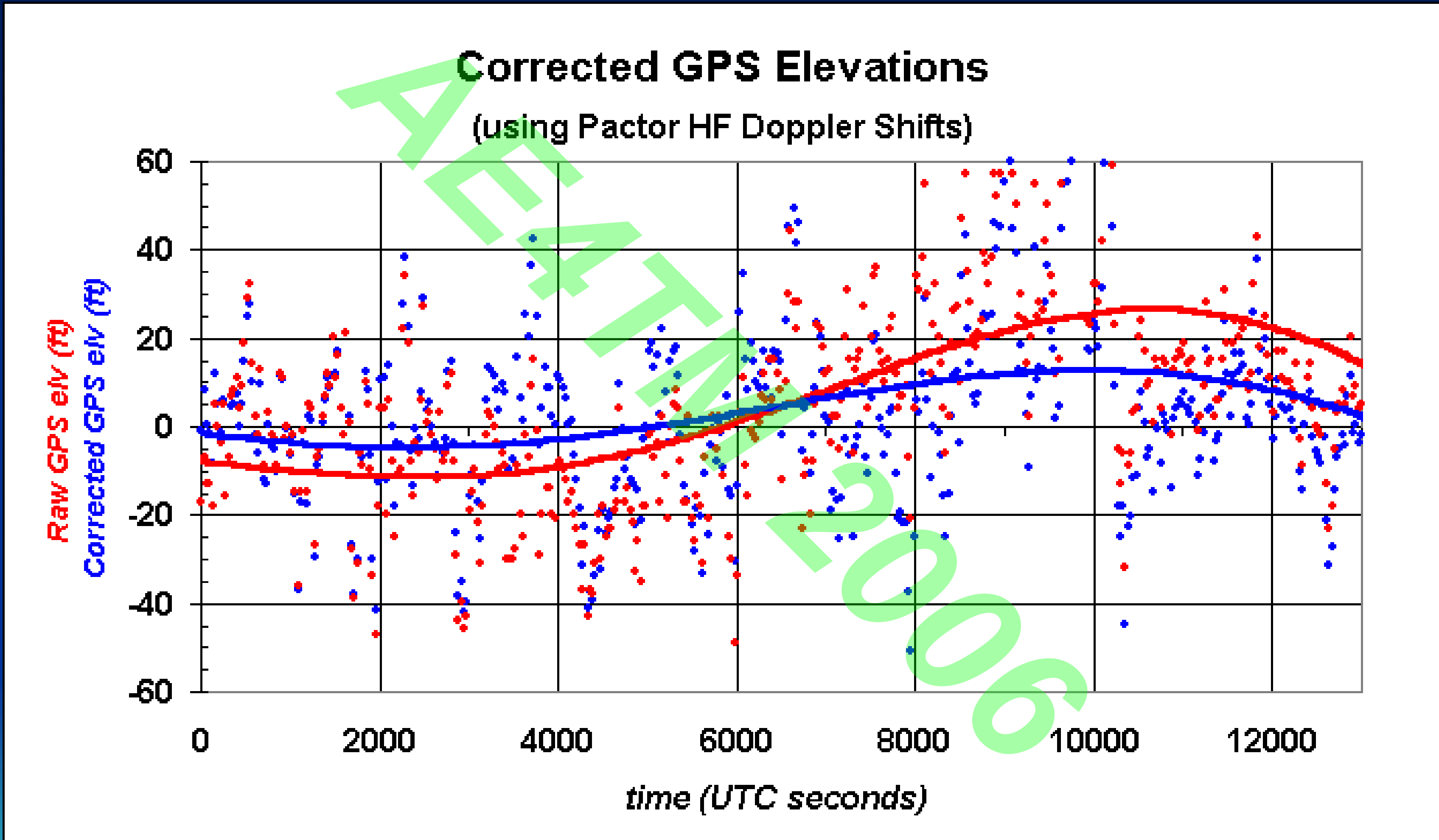








Corrected GPS Elevations



Transequatorial Spread-F (TE)

- Discovered in 1947
- Supports DX on 28MHz to 432 MHz
- Range is 3000 to 5000 miles
- Stations must be nearly equidistant across the magnetic equator
- Peak in contacts occur 5PM to 10PM near the spring and fall equinoxes, esp near the peak in the solar cycle
- Likely due to TID's from Conjugate Auroras

TE Spread-F from ARRL Handbook-1

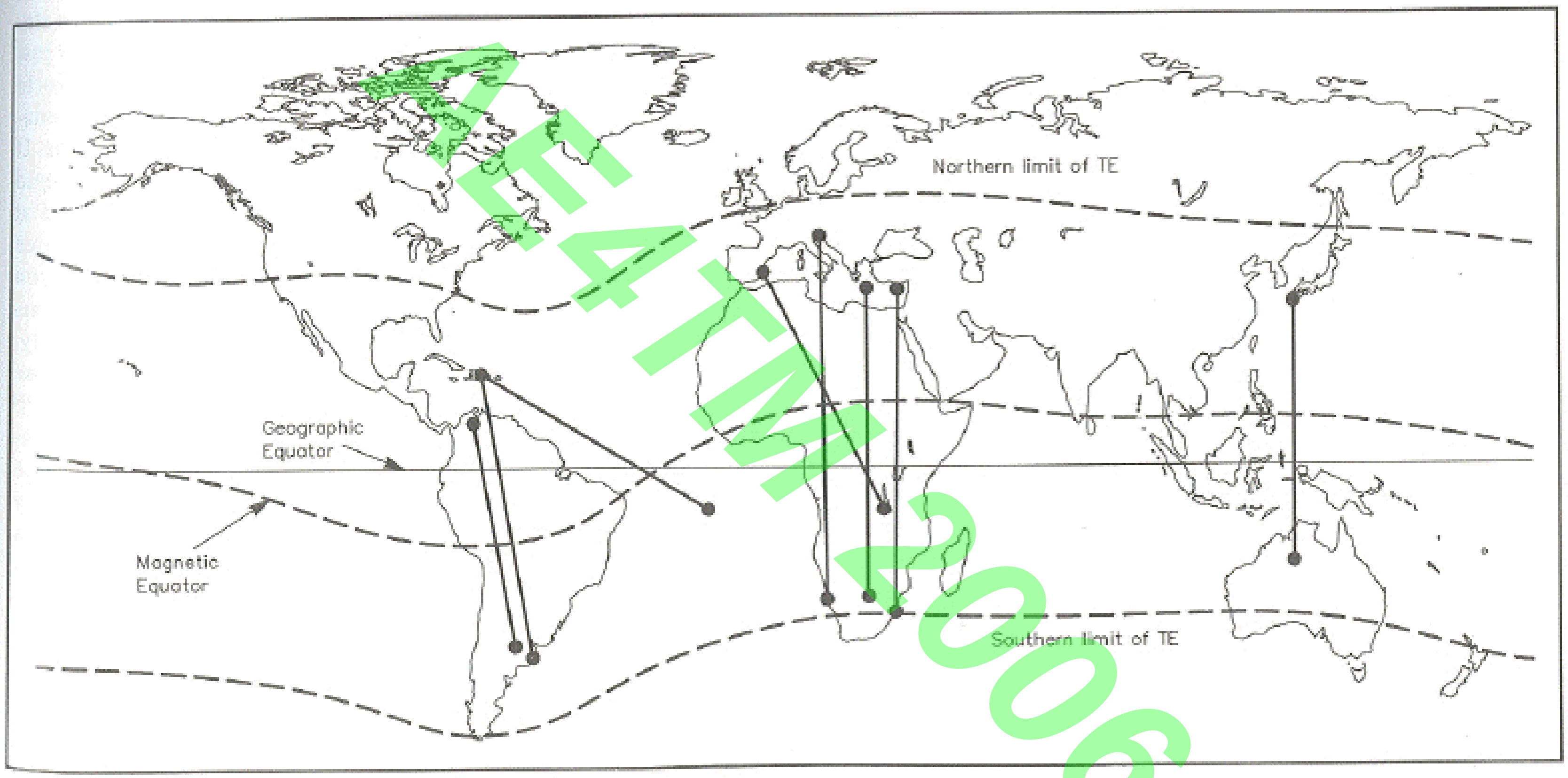
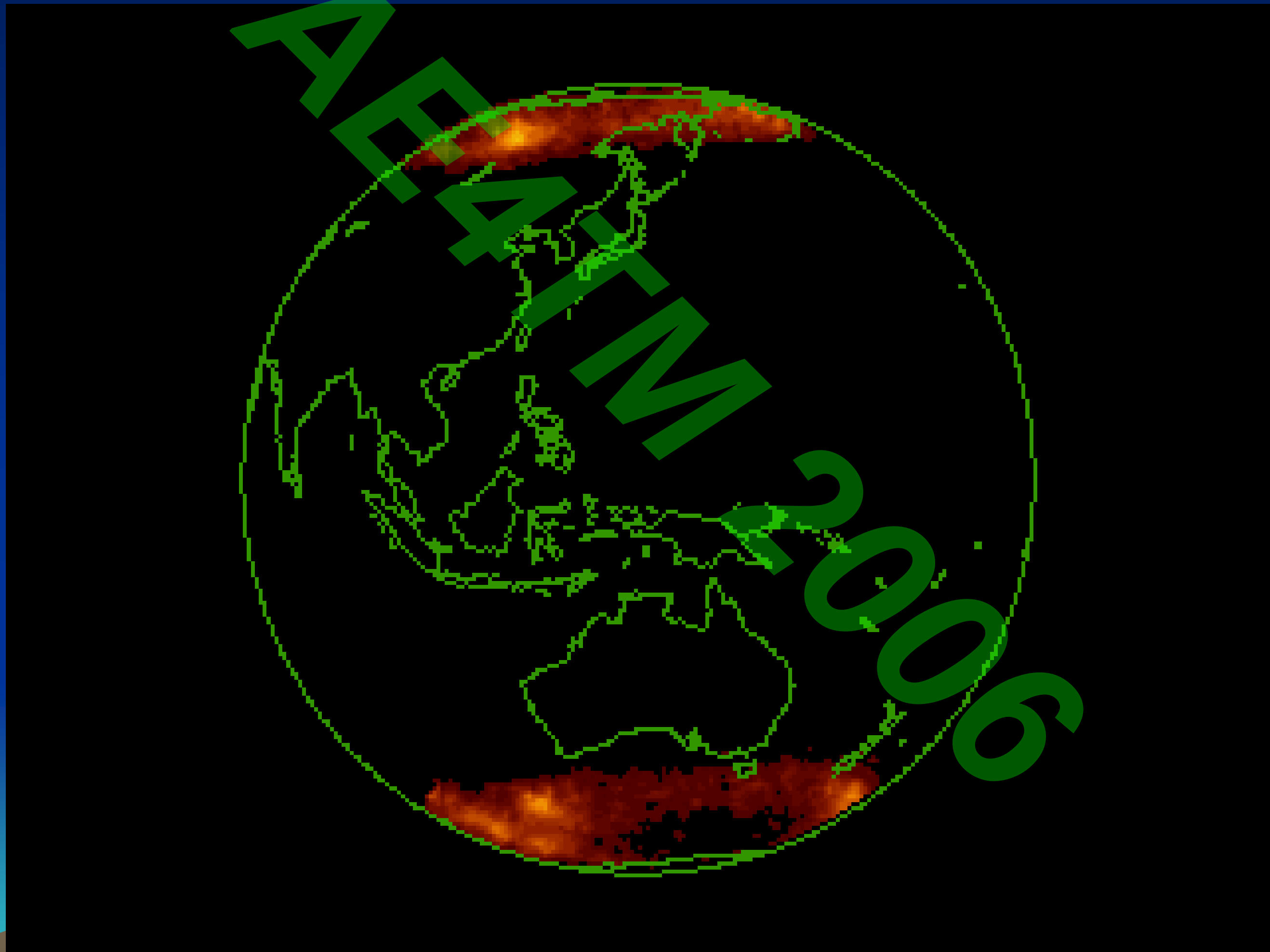


Fig 21.22—Transequatorial spread-F propagation takes place between stations equidistant across the geomagnetic equator. Distances up to 8000 km (5000 mi) are possible on 28 through 432 MHz. Note the geomagnetic equator is considerably south of the geographic equator in the Western Hemisphere.

Conjugate Auroras
(NASA Polar Spacecraft)



Source: http://www.gsfc.nasa.gov/topstory/20011025aurora.html

TE Spread-F from ARRL Handbook-2

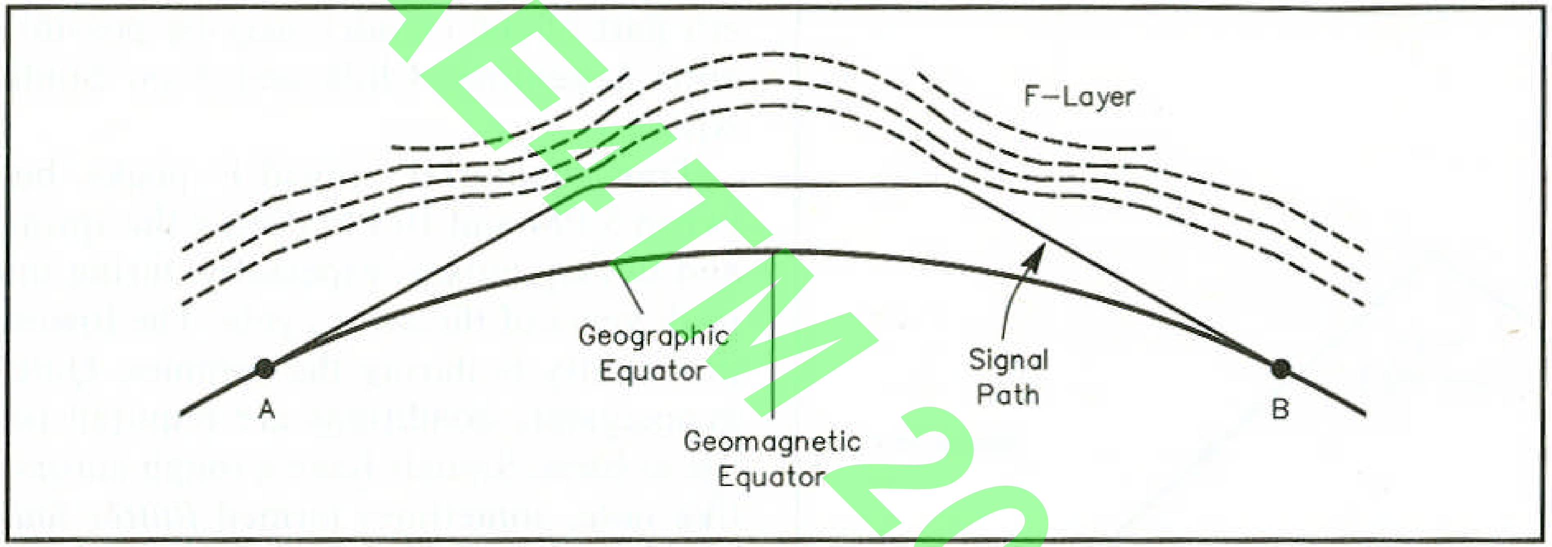
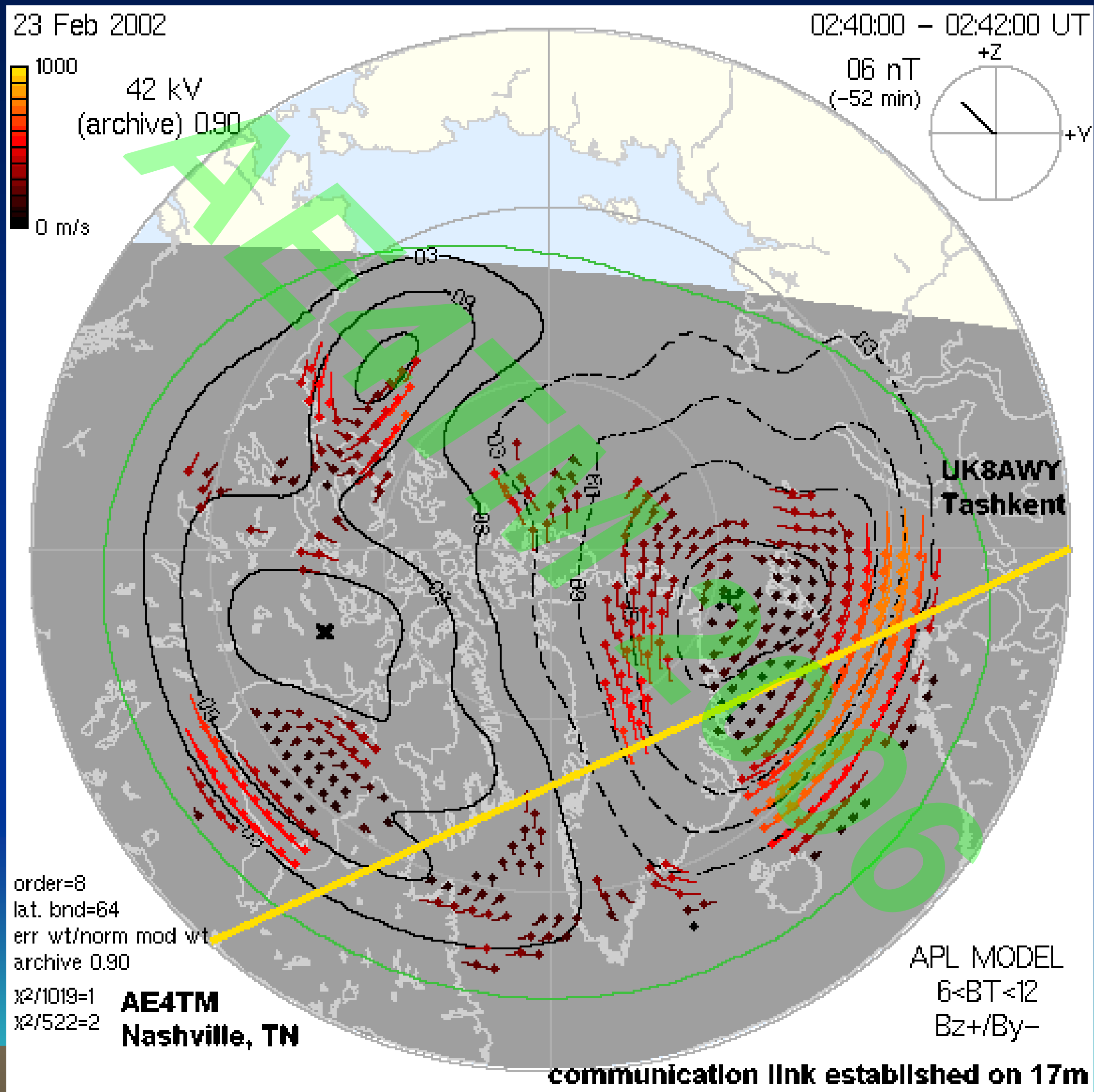


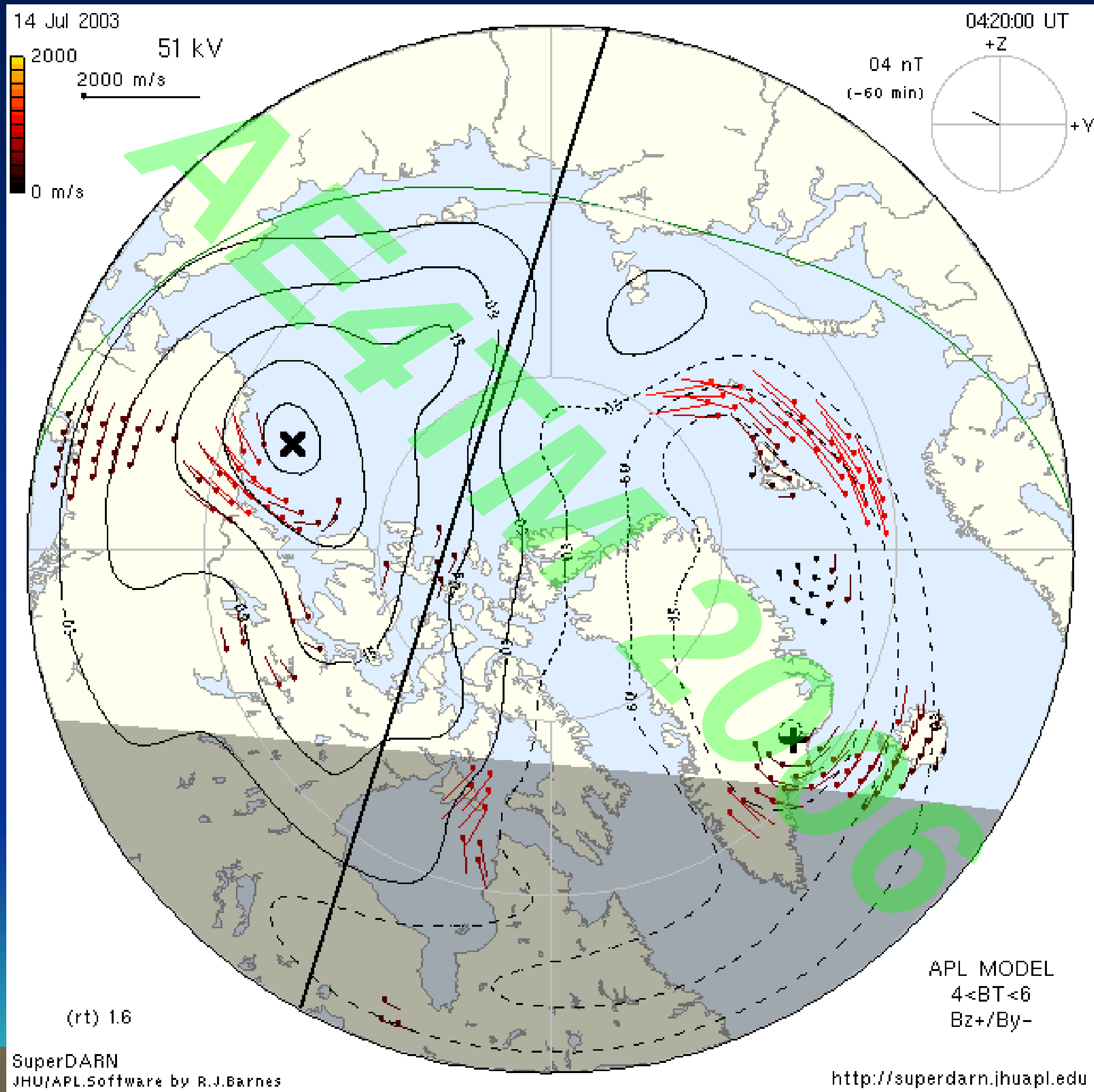
Fig 21.23—Cross-section of a transequatorial spread-F signal path, showing the effects of ionospheric bulging and a double refraction above the normal MUF.

Trans-Auroral HF Communications-1



Animation: http://ecjones.org/aurora.html

Trans-Auroral HF Communications-2



Animation: http://ecjones.org/aurora.html

Long Path Communications

Summary

- First joint study between amateur radio and SuperDARN OTHR program.
- Backscatter and TE propagation appear to be due to dense pockets of electrons escaping the auroral ovals during brief drops in the earth's magnetic field.
- Doppler fluctuations reveal movements of TID's as well as the rise/collapse of the ionosphere during the day.