Radio Aurora Explorer:

A CubeSat-based Ground-to-Space Bistatic Radar Experiment

Planned radar measurements

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Outline

1. Science objectives
2. Experiment description
3. Radar parameters
4. Radar angular and spatial resolution
5. Revised radar sensitivity calculations

Science objectives

1. What is the altitude distribution of high-latitude meter-scale ionospheric (electron density) irregularities?

2. To what extent are the irregularities magnetic field-aligned?

3. Which plasma waves are responsible for these irregularities?

4. What are the driving forces, e.g., electric field, density gradients?

Specific science objectives

1) What is the dependence of Farley-Buneman waves on driving electric fields and density gradients?

2) How are the parallel E field responsible for E region electron heating generated?

3) What is the role of electric fields and density gradients in the generation of F region irregularities?

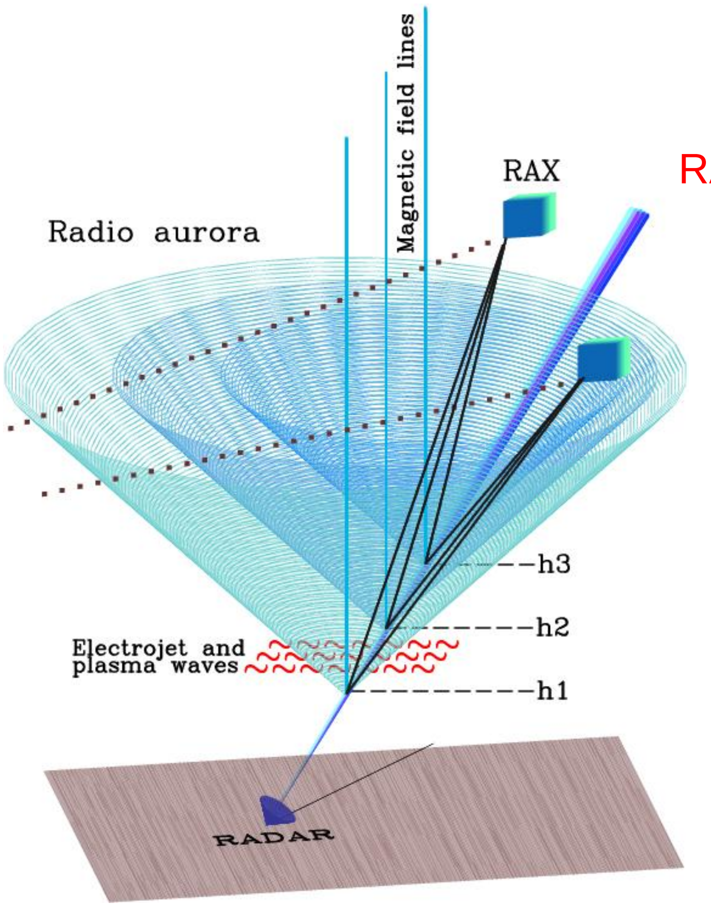
4) Is the Post-Rosenbluth instability operational in the F region?

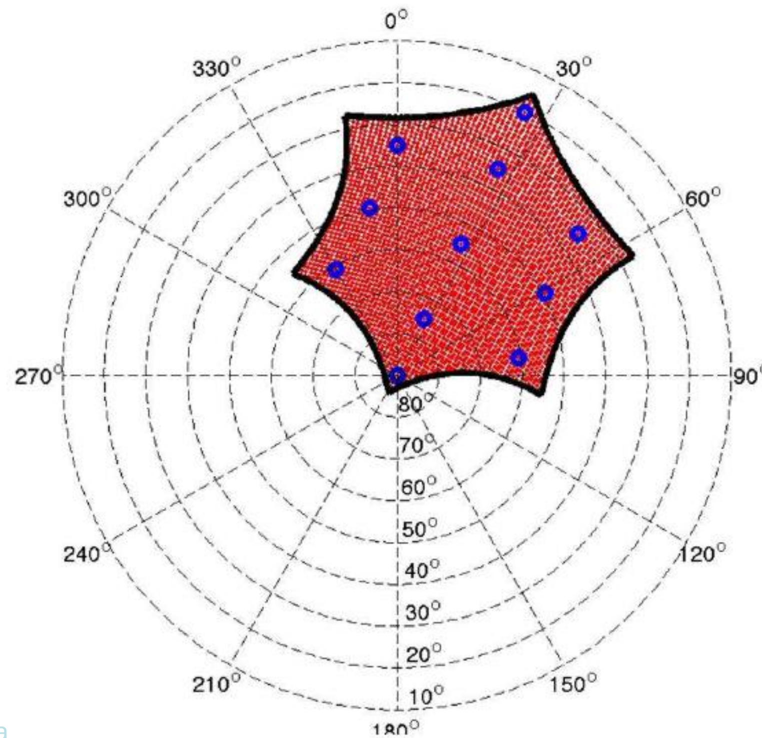
5) How much of F region artificial turbulence dissipated by parallel E fields?

Methodology and assumptions

1. Radar echoes originate inside the radar beam
2. Range gate the radar echoes to locate the target along the beam
3. Repeat at consecutive satellite positions to change the radar wave-vector with respect to B
4. Do above while measuring the background electric field and density gradient conditions

$$\underset{\text{RAX}}{I}\;(\underbrace{\mathbf{E},\, n_e,\, T_e,\, T_i,\, \theta}_{\text{PFISR}})$$





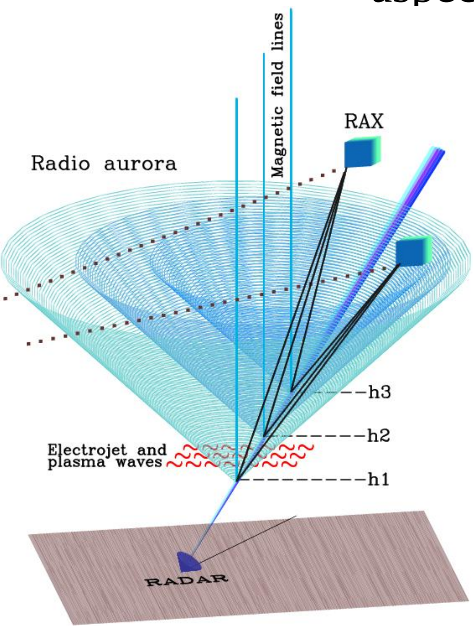
RAX radar parameters

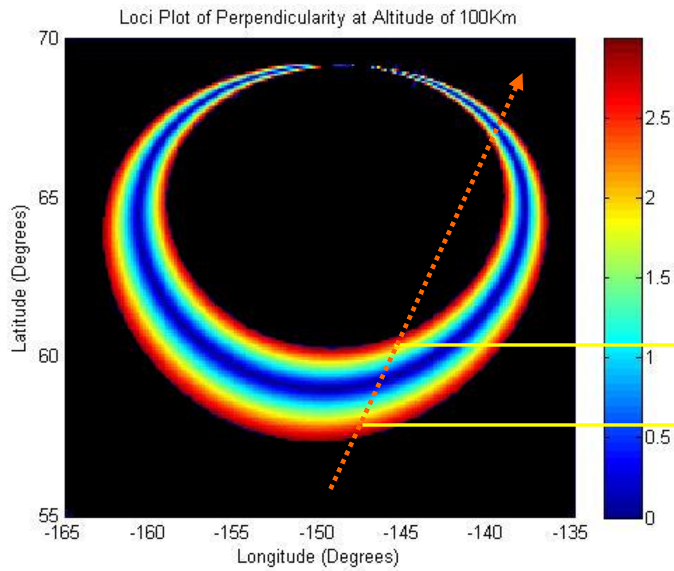
RAX radar receiver parameters	Value	Units
Frequency	426-510	MHz
Sampling frequency	1000000	I/Q samples/s
Altitude range	80-400	(km)
Wavelength	0.4-1.2	m
Max range resolution	3	km
Altitude resolution	3-5	km
Aspect angle resolution	1	degree
Aspect angle resolution after de-convolution	0.1	degree
Experimental zone radius at satellite altitude	~150 s/1200 km	
Duration of snapshot acquisition	~300s/2400 km	
Experiments per day per ISR	2-3	
RAX capability per day	1-2	
SNR range	-10 to 80	dB
Data options	Raw voltages, synchronized / unsynchronized matched filtering/incoherent integration, GPS or overflow based synchronization	
Pulse patterns	Single/multi pulse, single/multi beam Uncoded, 13-baud barker etc.	Reprogrammable Mode upgradable. Software upgradably.
Maximum snapshot acquisition time	500	S

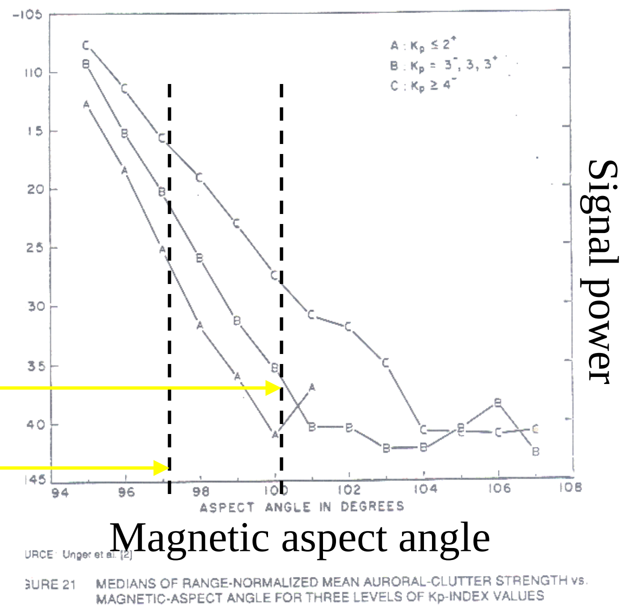
ISR	Location	Freq. MHz	PowerM W	BW	Inv. Lat.
PFISR	Alaska	449.0	2.0	1.0	78
RISR*	Canada	443.0	2.0	1.0	81
ESR	Norway	500.0	1.0	0.6	75
Millstone	Mass.	440.0	2.5	0.6	53
MUIR	Alaska	446.0	0.25	10	62*
Arecibo	Puerto Rico	430.0	2.5	0.2	34

Determination of magnetic field alignment

For a given altitude, the time series of measurements along the satellite track will determine how thick each wall is, determining the magnetic aspect sensitivity of the irregularities.

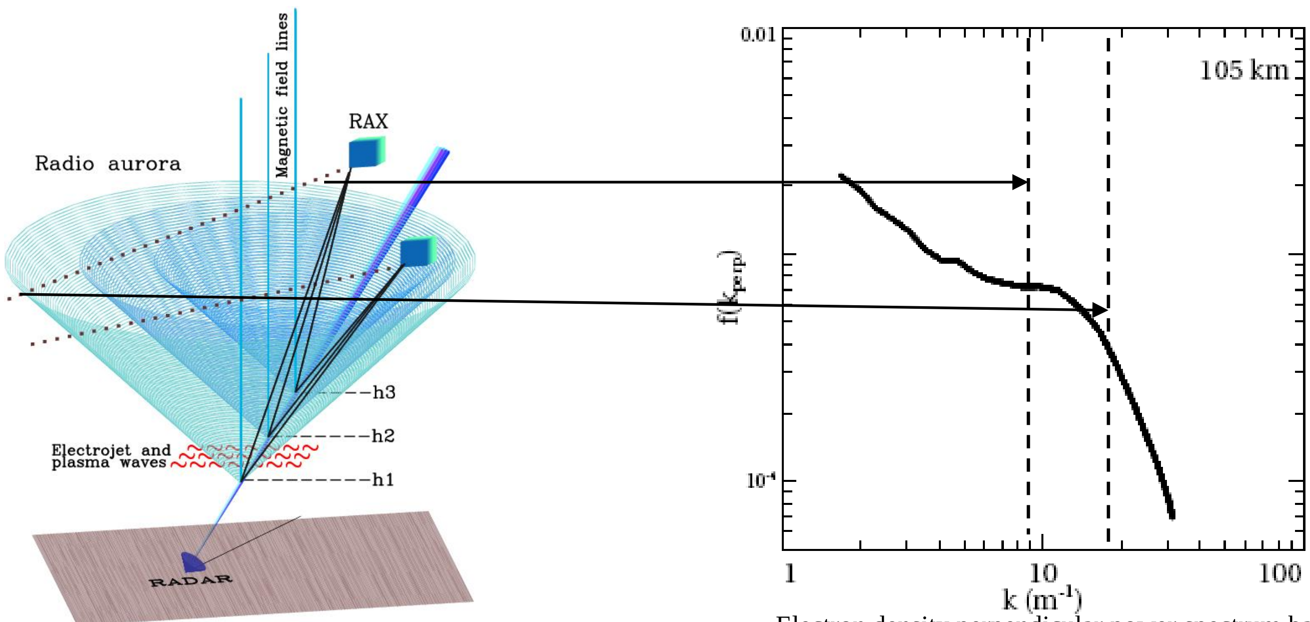






Determination of wavelength dependence

For a given altitude and magnetic aspect angle, the satellite will cross a cone at two points during a single experiment. The two crossings will provide measurements at two different radar Bragg wavelengths, corresponding to measurements at a pair of k-spectrum points.

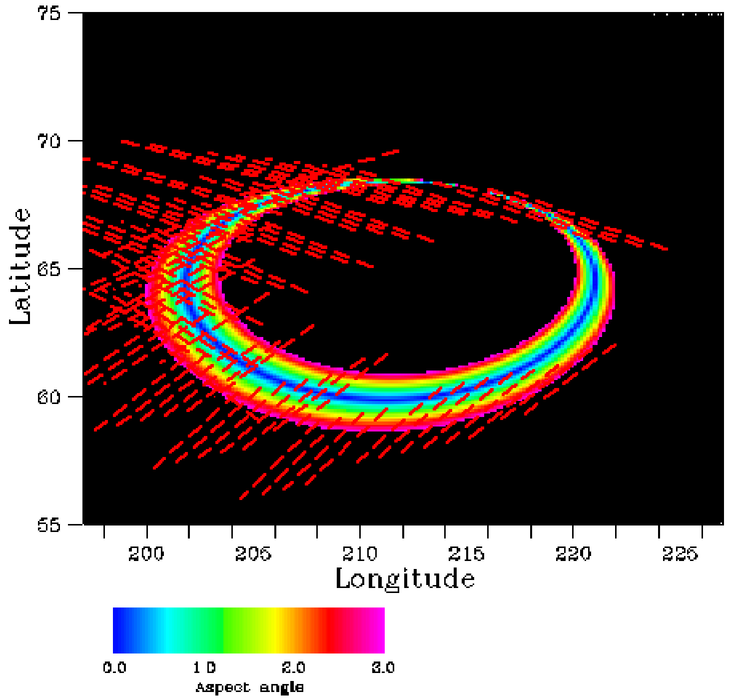


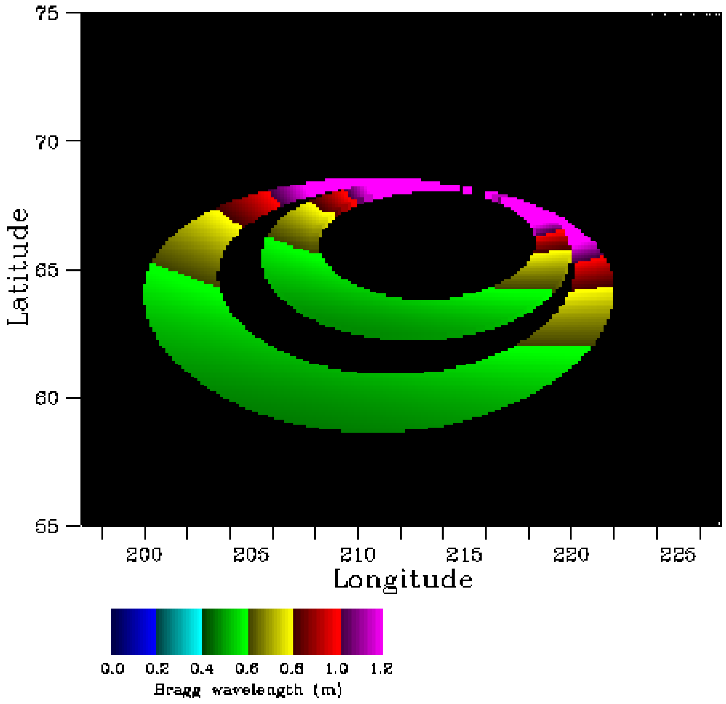
An illustration of the RAX scattering geometry in 3D.

Electron density perpendicular power spectrum based on ROSE rocket measurements [Bahcivan et al. 2009, submitted]

Experimental zone, wavelengths, and resolution

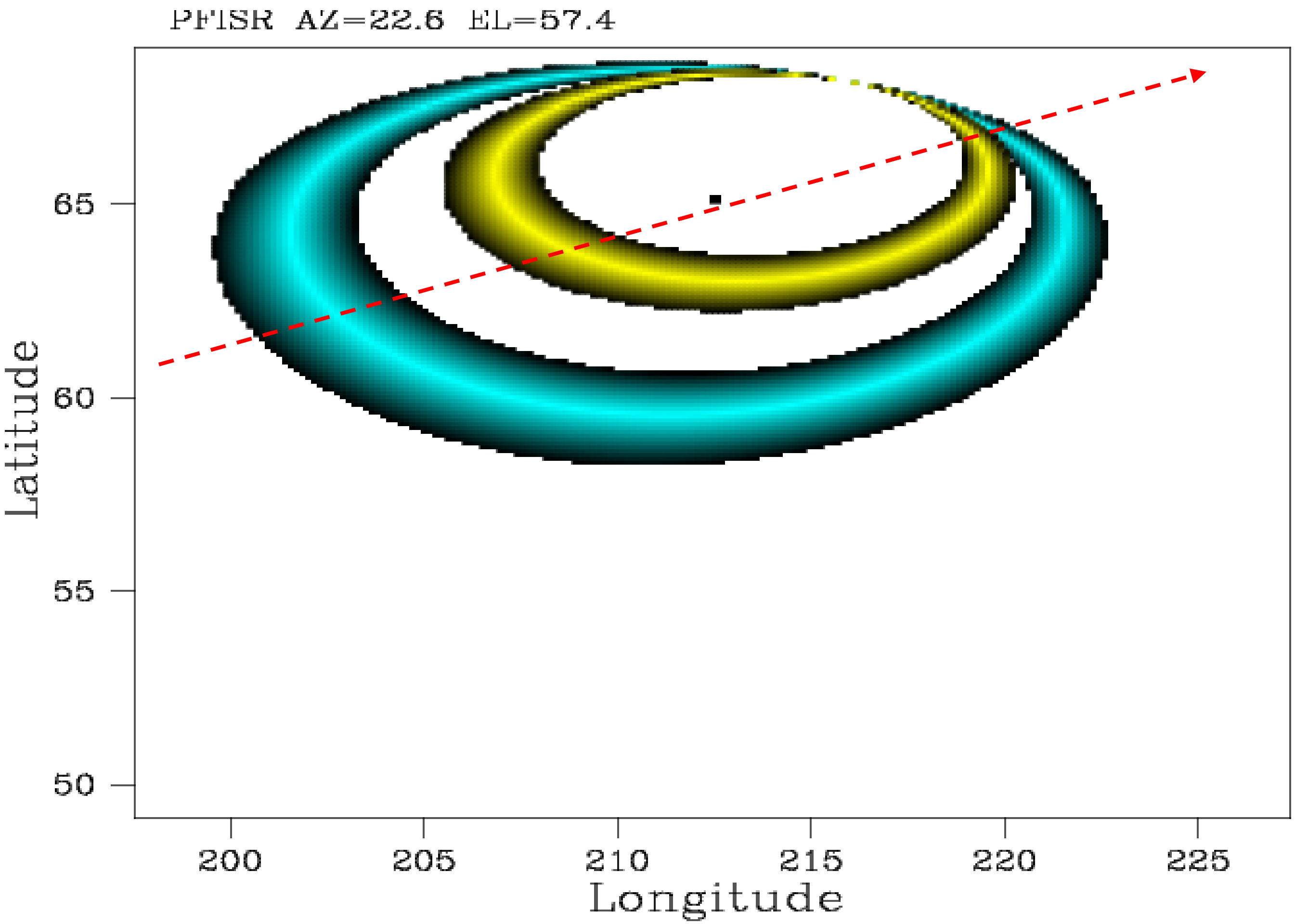
891 passes during the 11 month mission are in the vicinity of the scattering zone (aspect angle < 3 degrees, for irregularities at 100 km). The scattering zone contains Bragg wavelengths in the range from 0.4-2.0 m, with a concentration at 0.5 m.





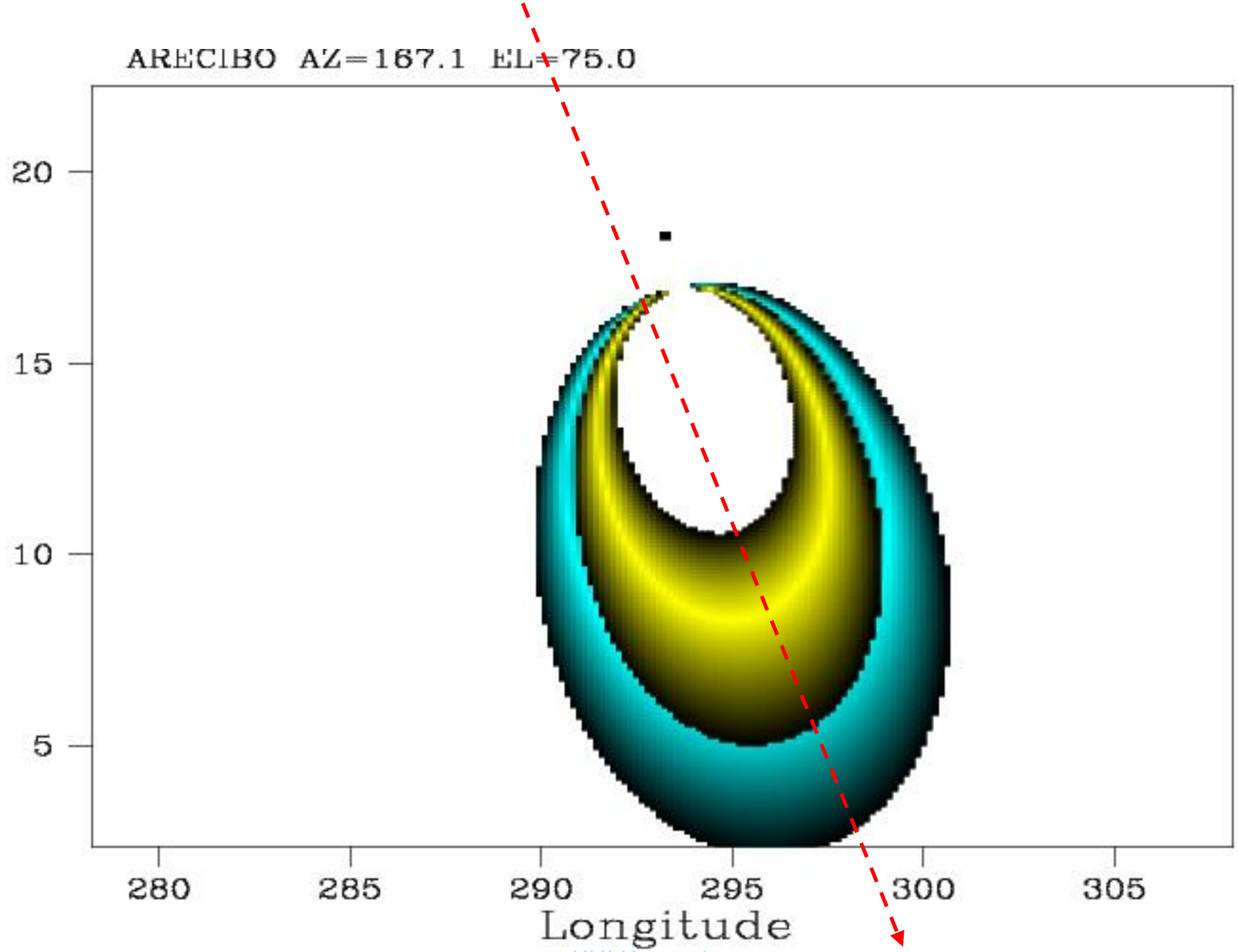
PFISR SINGLE BEAM

Transit time per degree aspect angle for perpendicular crossing: 2-5 sec.



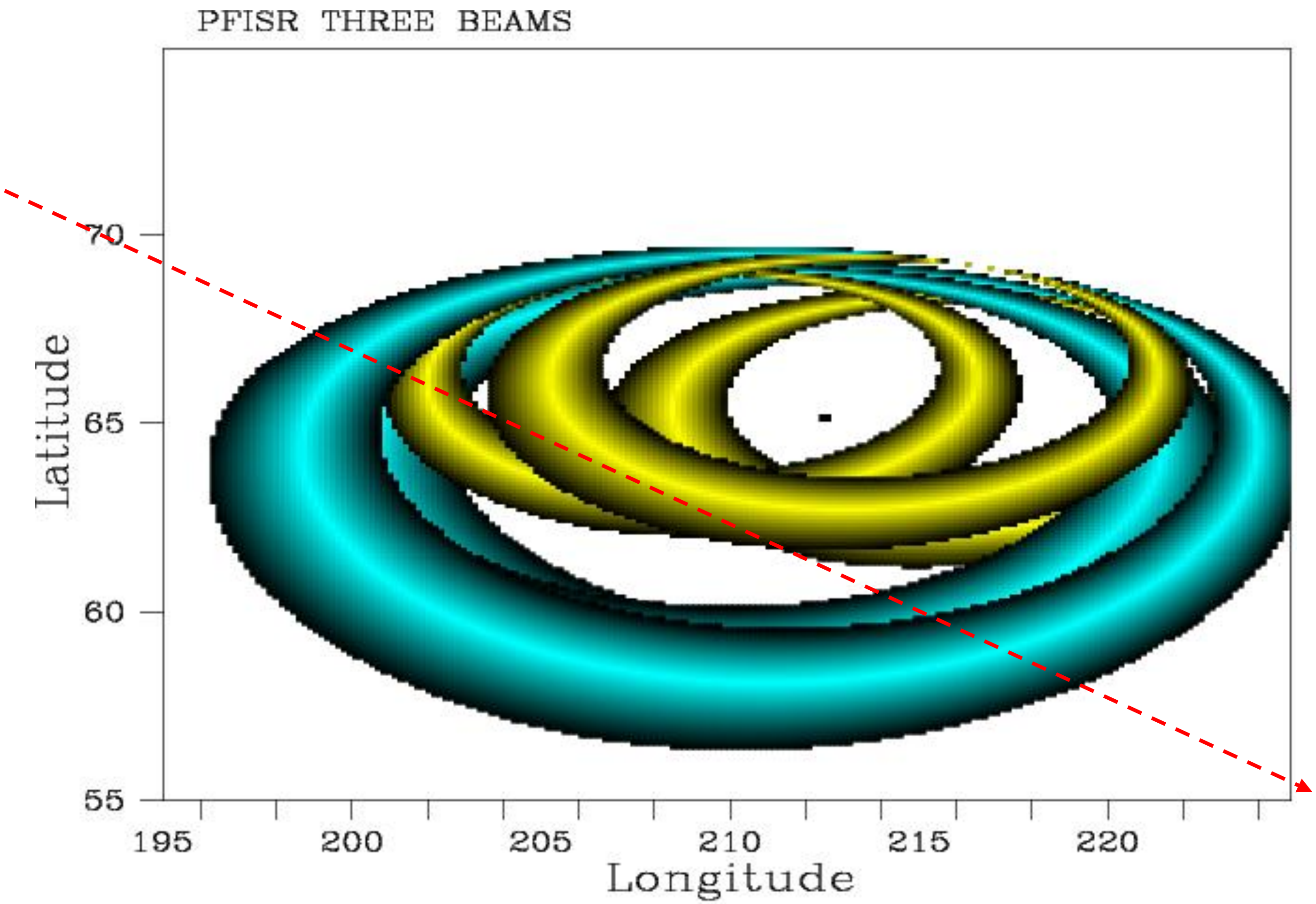
Arecibo

Transit time per degree aspect angle for perpendicular crossing: 10-15 sec.



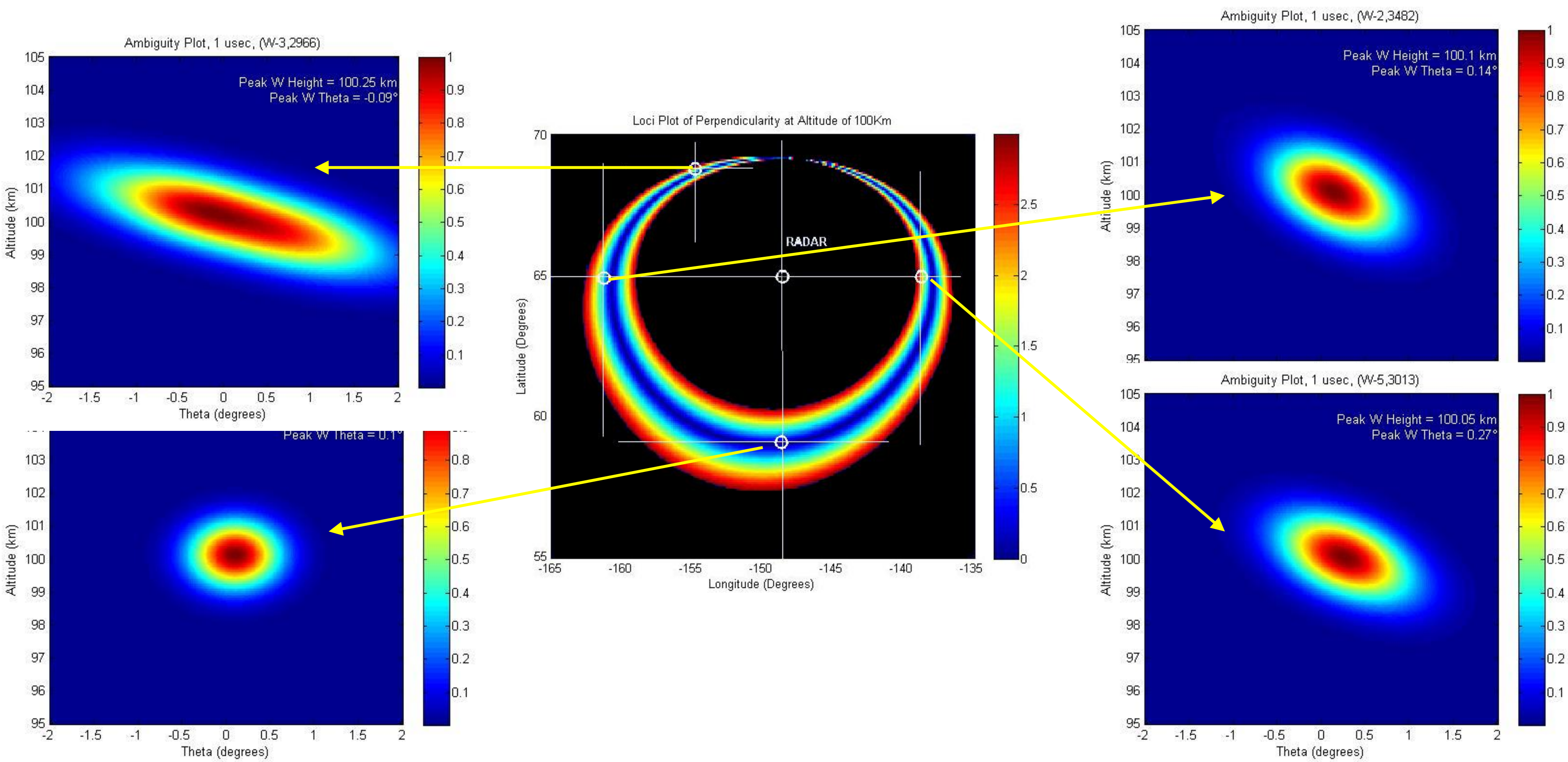
PFISR THREE BEAMS

Multiple AMISR beams can be used for more "detailed" illumination.



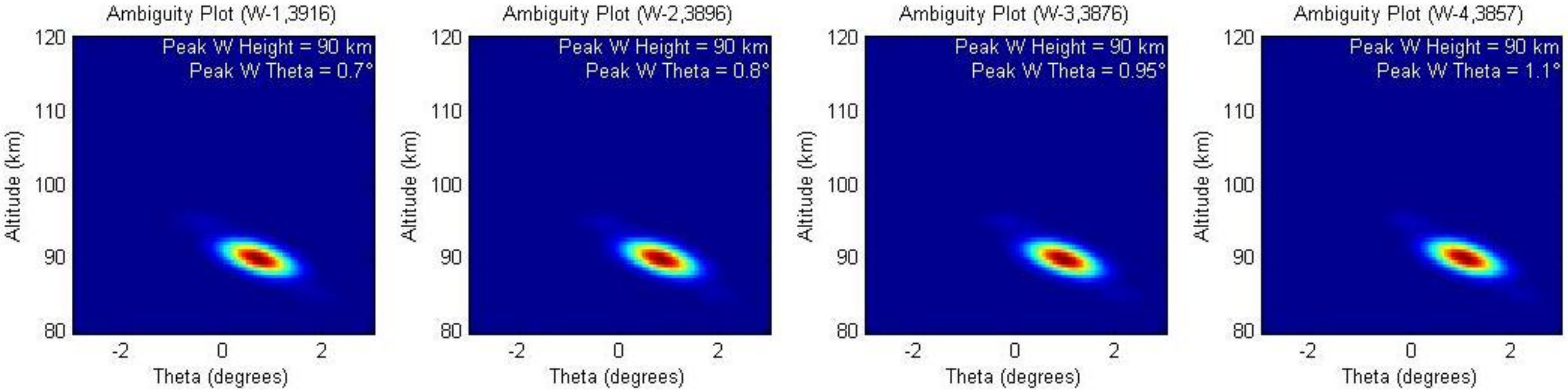
Radar resolution

Radar altitude-aspect angle ambiguity functions at various satellite positions in the scattering zone (~3-5 km and ~0.5°).



De-convolving the ambiguity function for high angular resolution

- Similar to the view of a telescope while observing the sky except we do not move the radar beam.



E region model for de-convolution test

$$S_{i,j}(h,\theta) = \sum_{h,\theta} \omega_{i,j}(h,\theta) * \underbrace{\left(\sum_{k=1}^{7} I_k e^{-\left(\frac{h-h_{0k}}{\Delta h}\right)^2} e^{-\left(\frac{\theta}{\Delta\theta_k}\right)^2}\right)}_{I\,(h,\,\theta)}$$

De-convolution test in the presence of noise and uncertainty

- Uncertainty : Due to random nature of scattering process.

$$\text{Uncertainty factor} = (1 + \text{randn} / \sqrt{N})$$

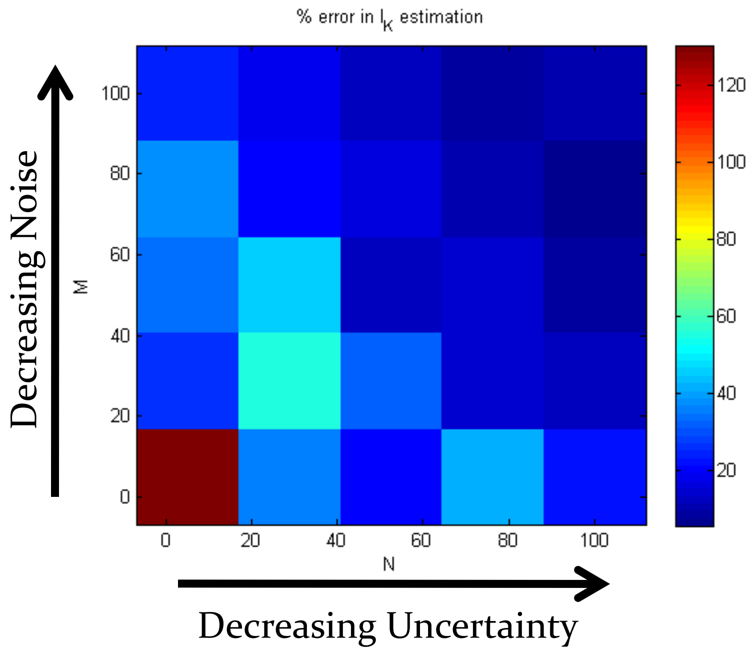
- Noise: System noise

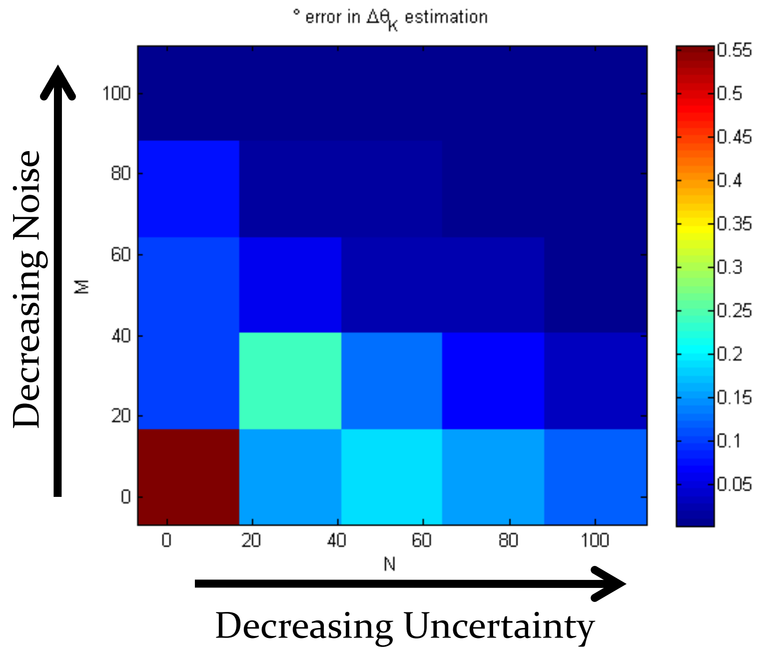
$$\text{Noise} = S_{i,j\,max} / M$$

$$S_{i,j} = (S_{i,j} + \text{Noise}) * (\text{Uncertainty factor})$$

De-convolution Results

Plot of error in de-convolution due to noise and uncertainty.





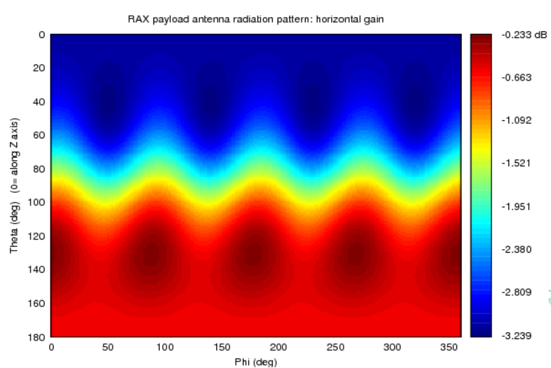
10% error margin in irregularity intensity and 0.1° error margin in aspect angle.

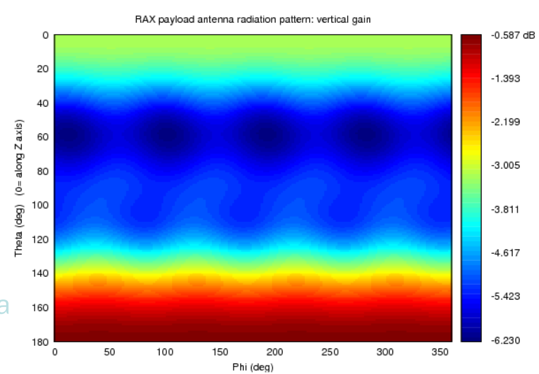
Measurement of absolute scattering coefficients

(1) Absolute intensity measurements requires the specification of the antenna gain for a given scattered signal polarization defined by the eccentricity and the direction of the polarization.
(2) The eccentricity is obtained from the scattering geometry.
(3) The polarization direction is obtained from the geometry and the estimated Faraday rotation based on the ISR TEC measurements.

$$E_s = |E_\theta| e^{i(\omega t)} \hat{\theta} + |E_\phi| e^{i(\omega t + \pi/2)} \hat{\phi}$$

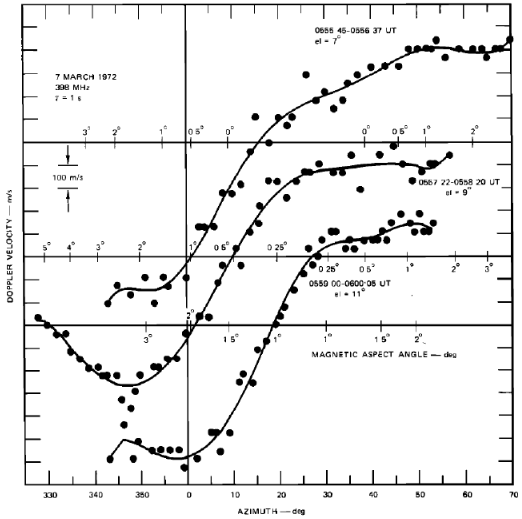
$$G_r(\theta, \phi) = (G_\theta(\theta, \phi)|E_\theta|^2 + G_\phi(\theta, \phi)|E_\phi|^2)/(|E_\theta|^2 + |E_\phi|^2)$$



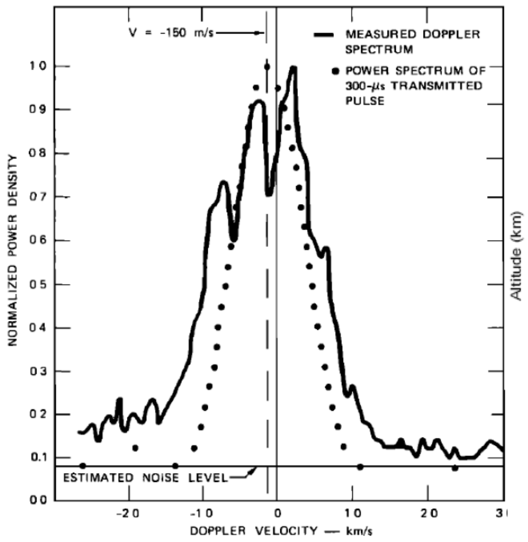


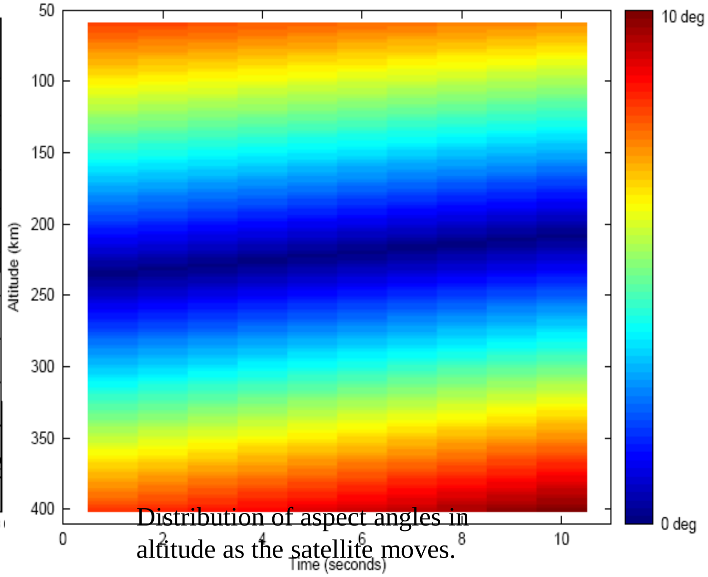
Doppler measurements

(1) Spectral shift of the irregularities is between -400 and 400 m/s.
(2) Spectral width is between 0 and 400 m/s.
(3) At 0.5 m Bragg wavelength, the correlation time is > 1.25 ms
(4) Range aliasing restriction is ~500 μs (for <3° aspect angles).



Doppler measurements from
Homer radar [Tsunoda, 1976]





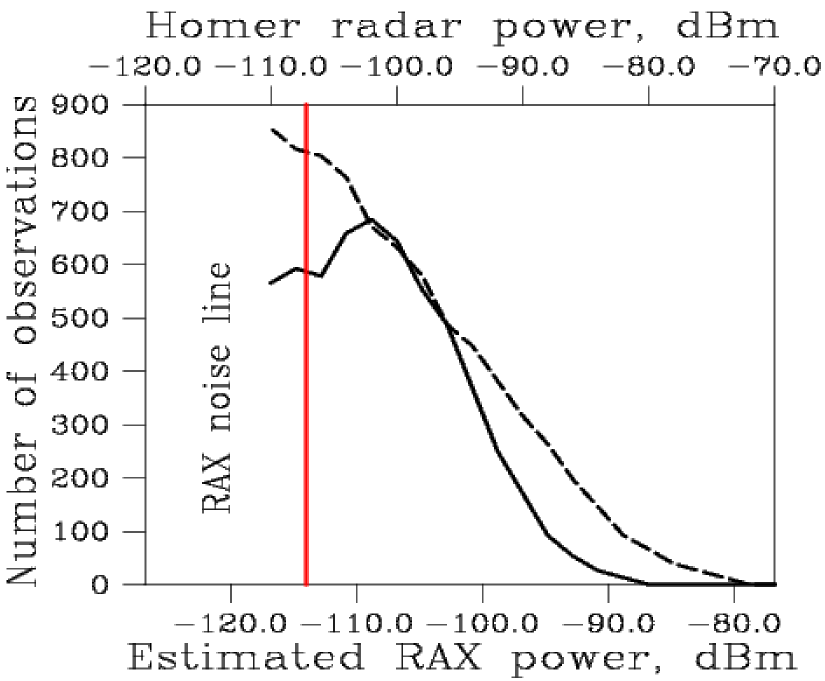
Distribution of aspect angles in
altitude as the satellite moves.

Revised Sensitivity Calculations

The sensitivity of the RAX-PFISR bistatic radar is comparable to that of UHF Homer radar, whose power statistics are shown on the right.

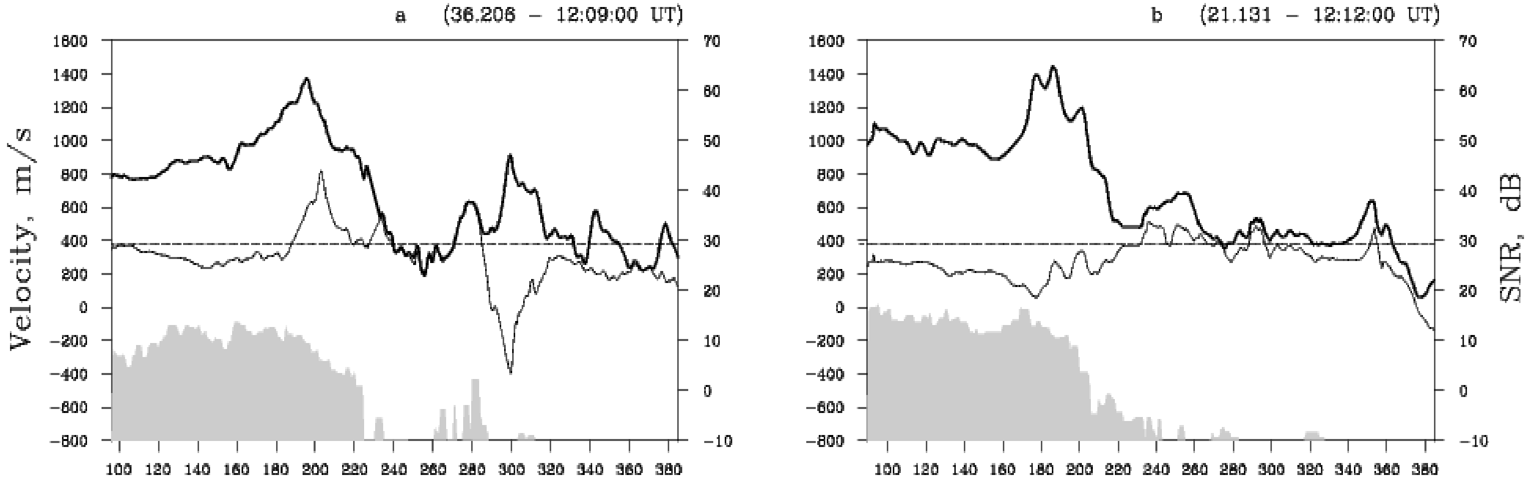
	RAX	Homer	Unit
P_t	2×10^9	4×10^7	mW
L	1.00	0.63	-
G_t	20000	3981	-
V_s	9.00×10^{11}	1.45×10^{13}	m^3
σ	1.94×10^{-9}	5.34×10^{-10}	m^{-1}
G_r	1	3981	-
λ	0.670	0.754	m
R_1	150	800	km
R_2	1000	800	km
P_r	-81	-76	dBm
P_n	-114	-115	dBm
SNR	33	39	dB

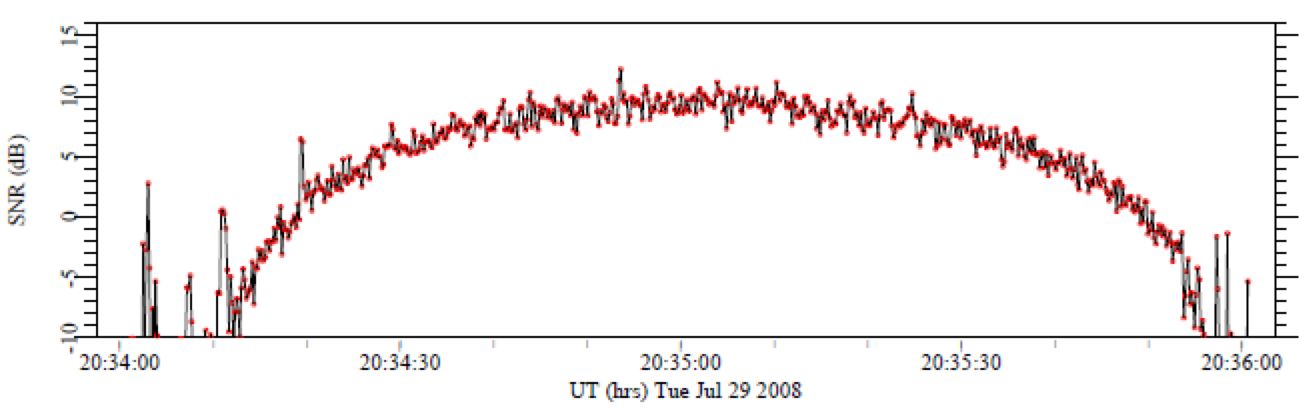
RAX radar sensitivity compared with Homer radar's for statistically maximum SNR.

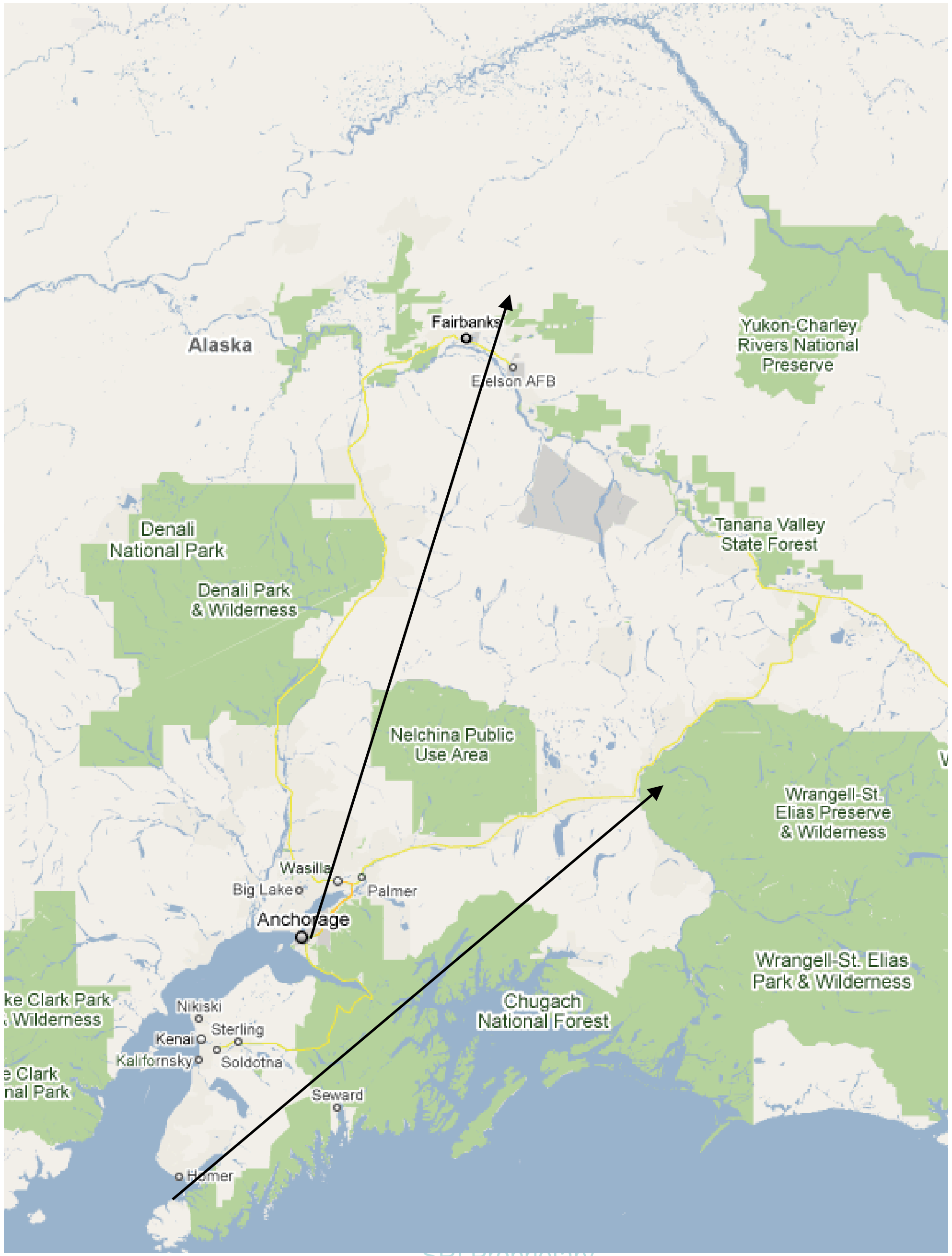


The distribution of observations as a function of receiver power [Moorcroft 1987] based on two separate time windows of Homer radar measurements. The bottom axis is shifted to interpret the data for RAE.

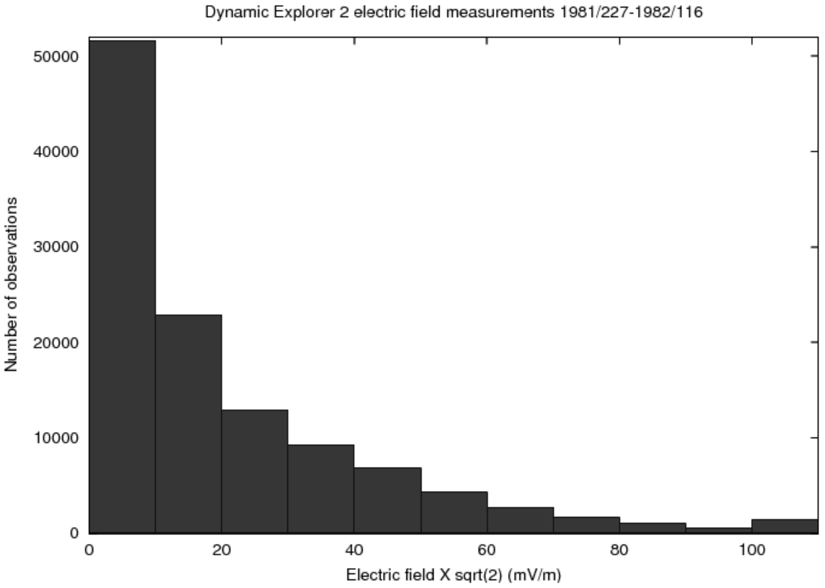
Relative intensities of natural and artificial E region irregularities






Alaska
Fairbanks
Eielson AFB
Yukon-Charley Rivers National Preserve
Denali National Park
Denali Park & Wilderness
Tanana Valley State Forest
Nelchina Public Use Area
Wrangell-St. Elias Preserve & Wilderness
Wasilla
Big Lake
Palmer
Anchorage
Wrangell-St. Elias Park & Wilderness
Nikiski
Sterling
Kenai
Kalifornsky
Soldotna
Chugach National Forest
Seward
Homer

Statistics of electric fields at PFISR and RISR



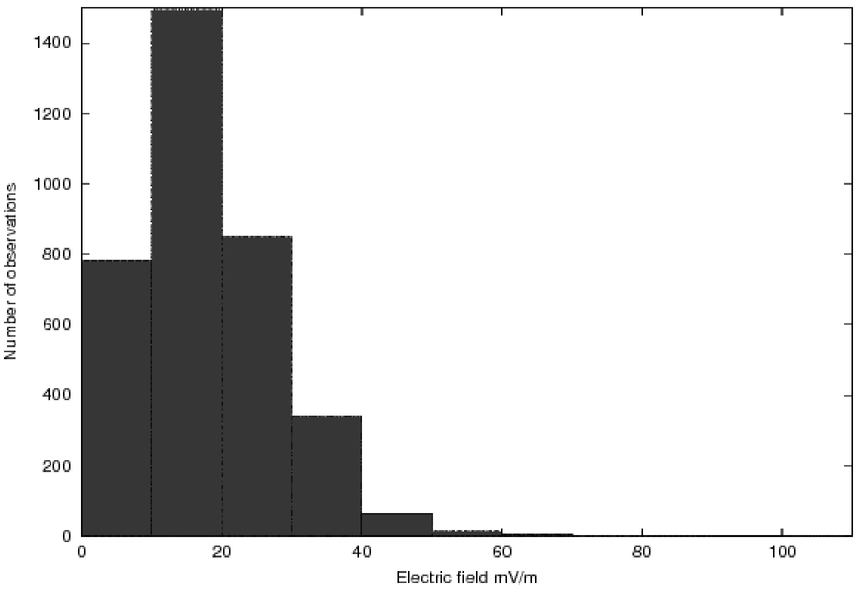
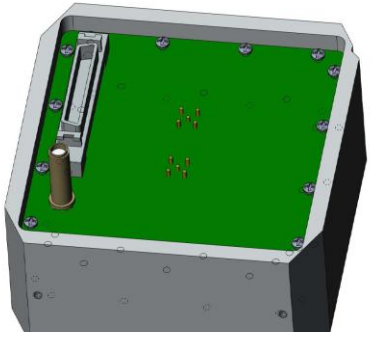
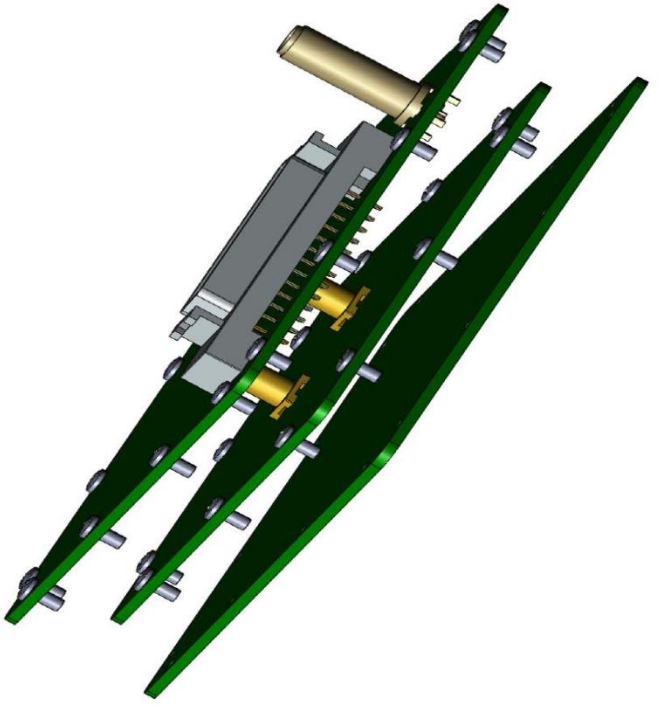


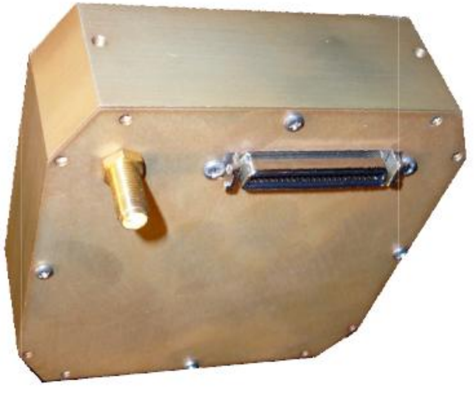
Figure 5. Electric field statistics in the vicinity of PFISR.

Payload Receiver

Primarily Analog Industrial Components
• Pulse (>2µS) or CW operation
• 426 – 510 MHz (1 MHz steps)
• 4-bands
• Adjustable Gain
• Internal Voltage Regulation
• Continuous Sampling at 14-bit Resolution
• In-phase and Quadrature (I/Q) Signals
• Internal 500 MHz Calibration Source

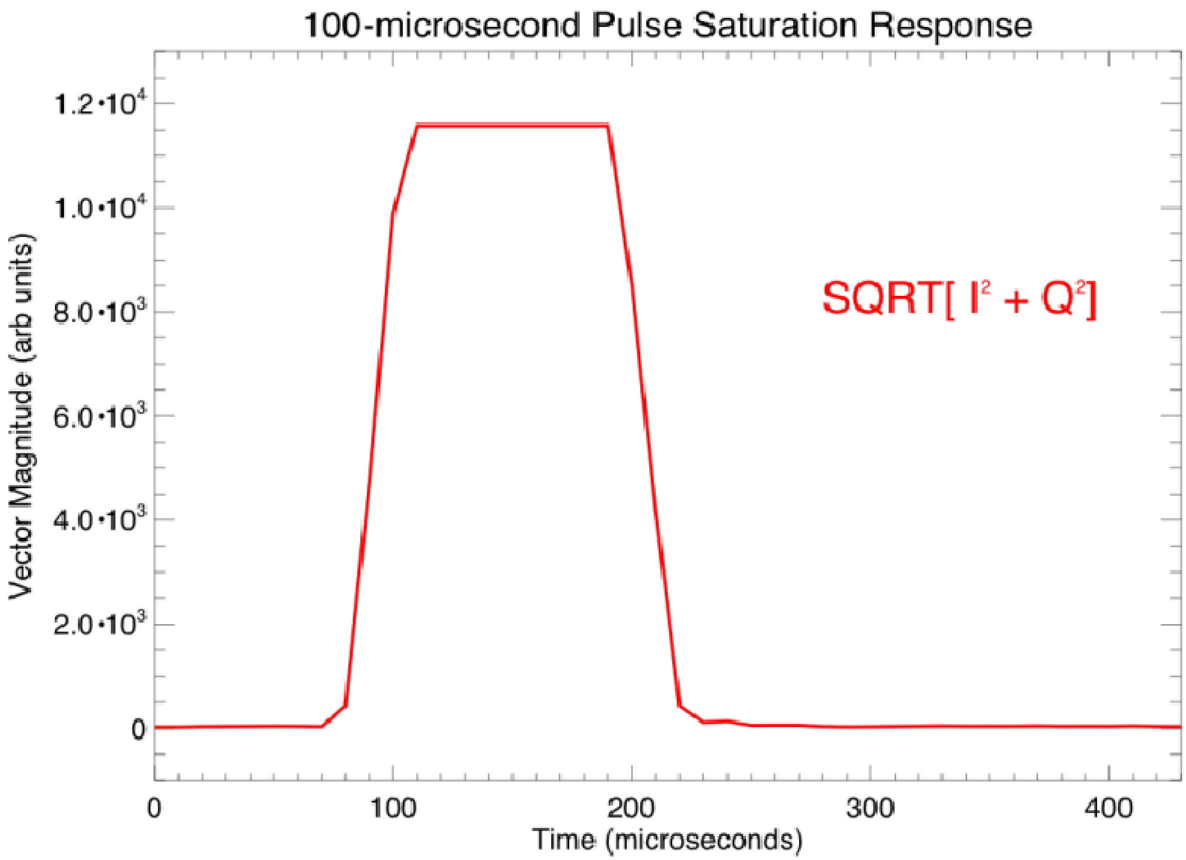


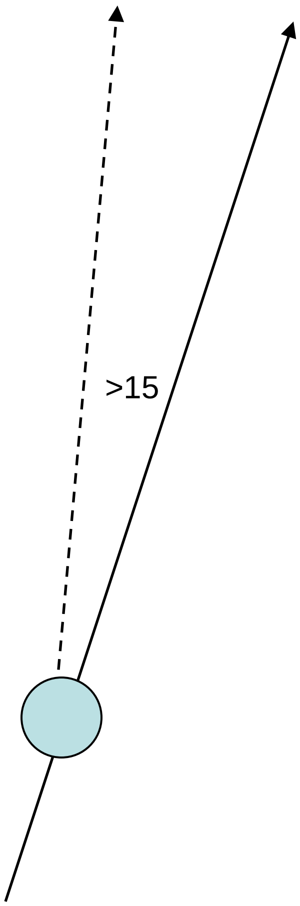




Provides EMI Shield
• Thermally Dissipative
• 9.7cm x 9.7cm x 3.6cm
• Weight 320 g
• Power 2.6 W

Recovery from direct hit





Experiment plans after satellite launch

1. Test low resolution radar modes with PFISR

2. Begin 6 months of PFISR-RAX experiment schedule of 2-3 experiments per day. Process only those that E exceeds 20 mV/m. If F region echoes observed for below threshold electric fields, process all. The goal is to obtain sufficient statistics for

3. I(E, ne, theta, h)

4. Solicit experiments from community, natural and artificial irregularities, at mid-latitudes and high latitudes.