Ice surface roughness modeling for effect on radio signals from UHE particle showers

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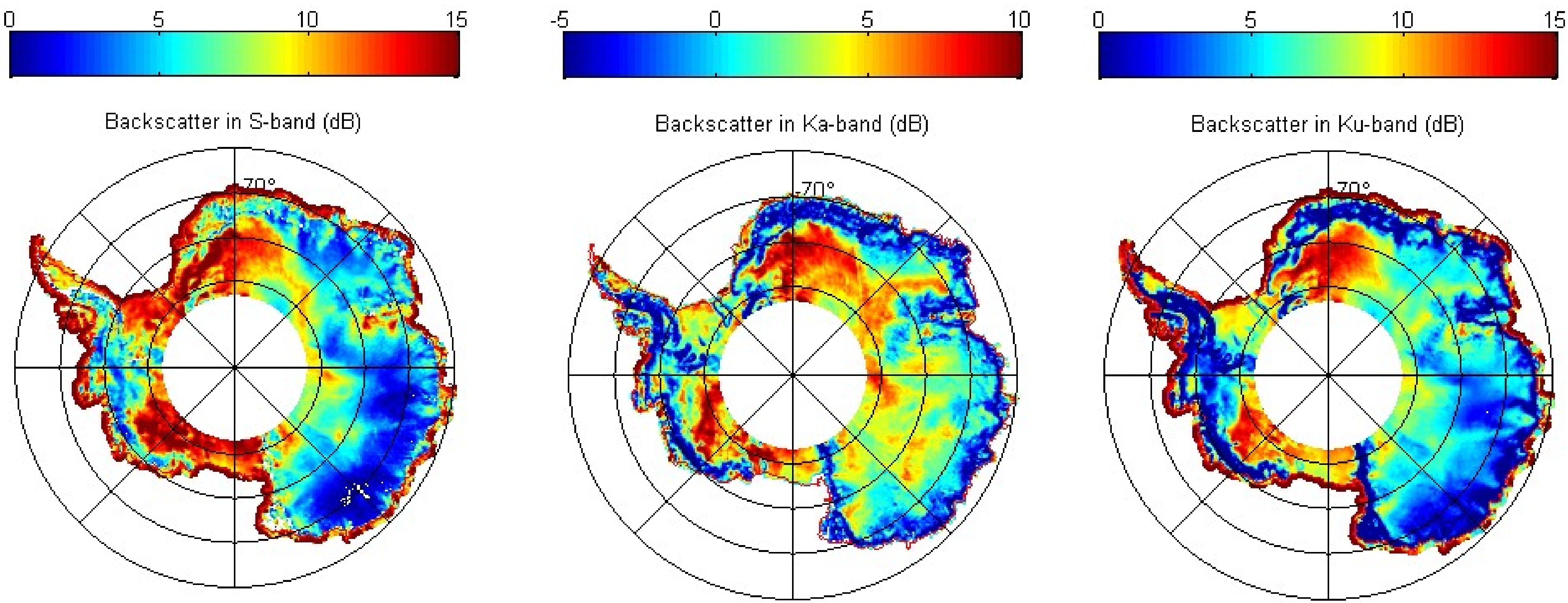
- **ANITA is looking RF pulses from in-ice neutrinos events and has observed reflected CR events**
- **Frequency spectrum of RF pulses are used for event reconstruction**
- **Surface features have scale lengths comparable to the wavelength regime of ANITA and may lead to frequency dependent decoherence**

- What we want: continent wide measurements that can determine frequency dependence of decoherence in the 0.2-1.2 GHz range
- What we have:
  - 0.2 – 1.2 GHz: ANITA direct and reflected solar signal. Limited coverage, no frequency dependence within band. Measured by ANITA.
  - 2.0 – 3.0 GHz: In-lab measurements.
  - 2.0 – 4.0, 12.0 – 18.0, 27.0 – 40.0 GHz: satellite backscatter, sensitive to large scale topography (>m) and ice grain/density. Full continent.
  - Wind speed and direction over full continent, not correlated to ANITA scales.
  - Photographic images: CreSIS and Russian traverse, down to cm scale resolution. Limited coverage

Backscatter data

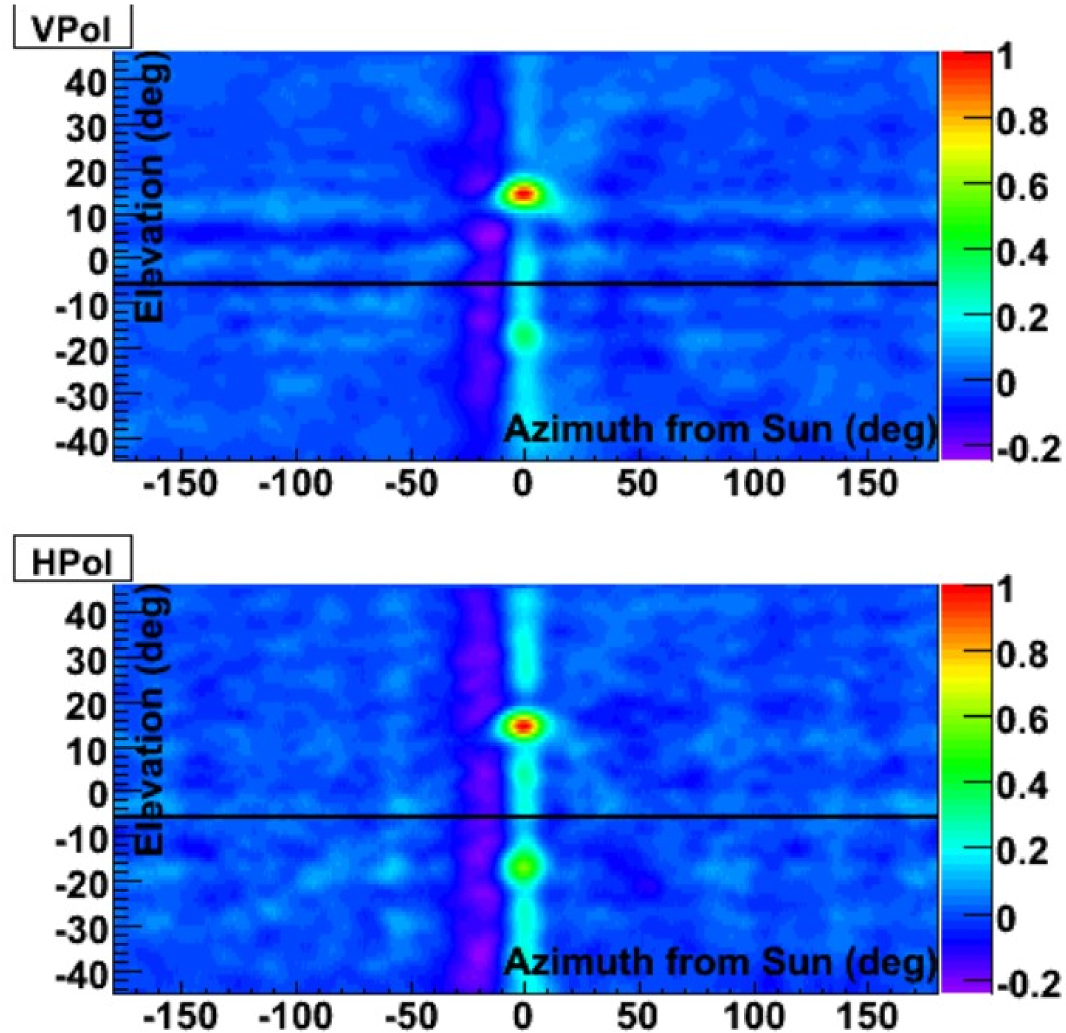
- S-band is directly useful for comparing result from the photographic data
- Volume echo increasingly more important with decreasing frequency
- Correlations across bands probably due to larger topographical features



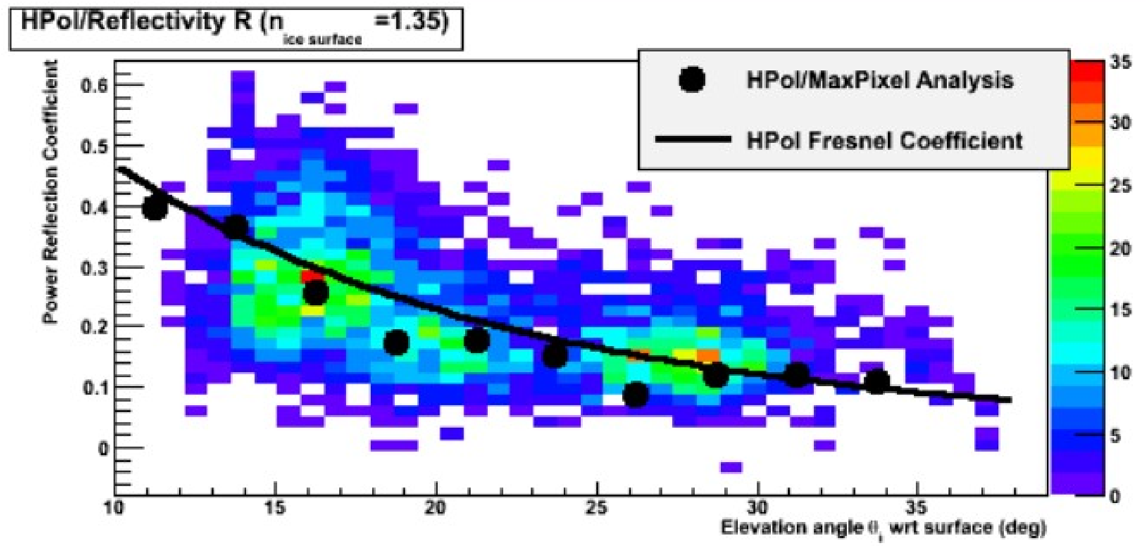
2-4 GHz 12-18 GHz 27-40 GHz

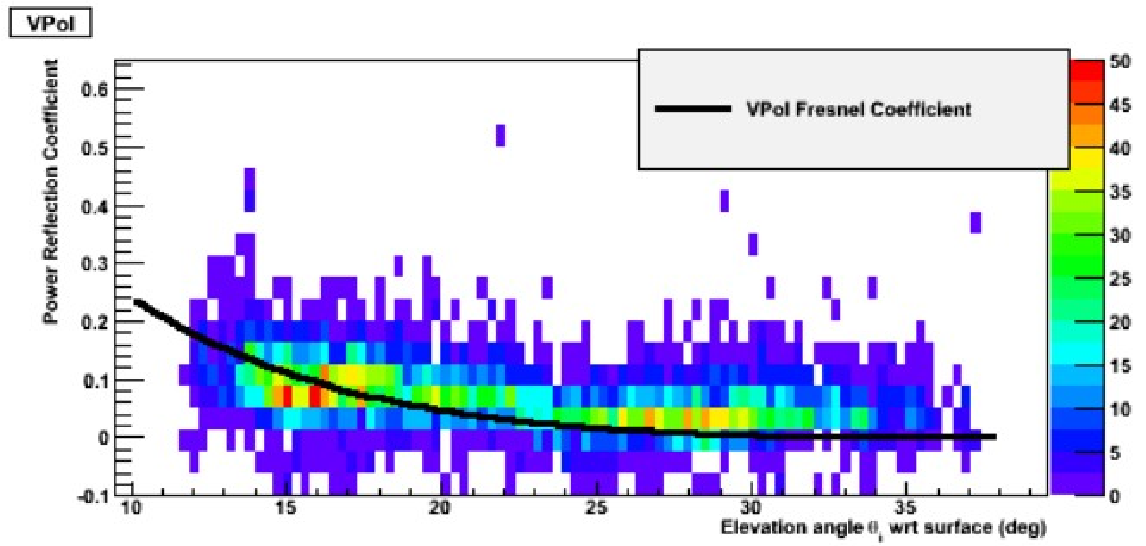
Measuring Reflection coefficients with ANITA

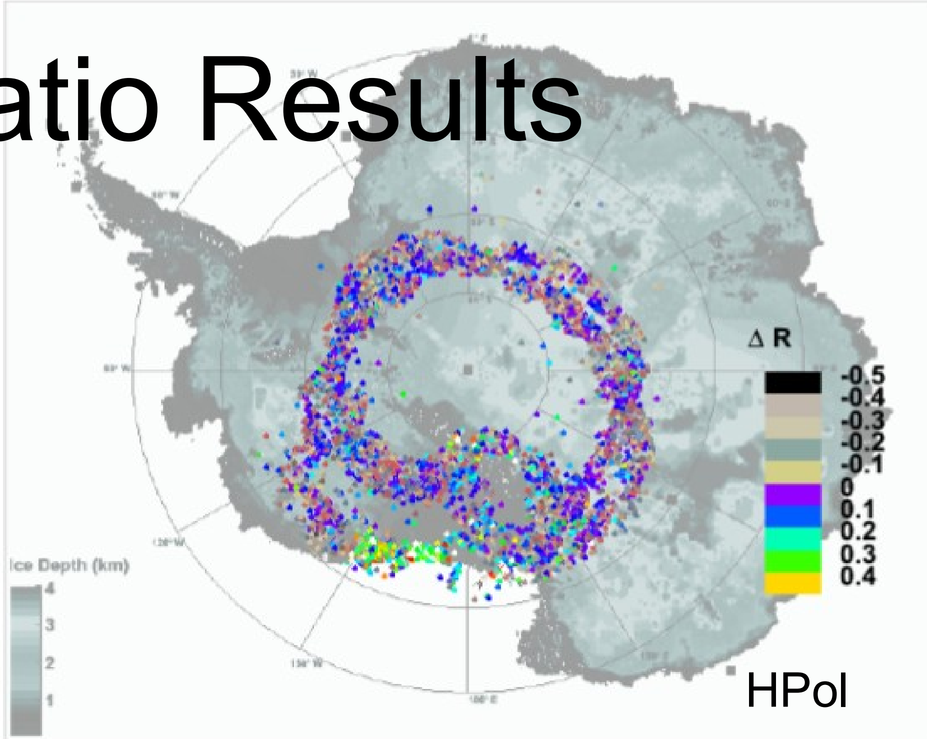
- Dual polarized horns
- Track Sun and solar reflection point determine location dependent coefficients
- No large deviations from Fresnel were measured over continent

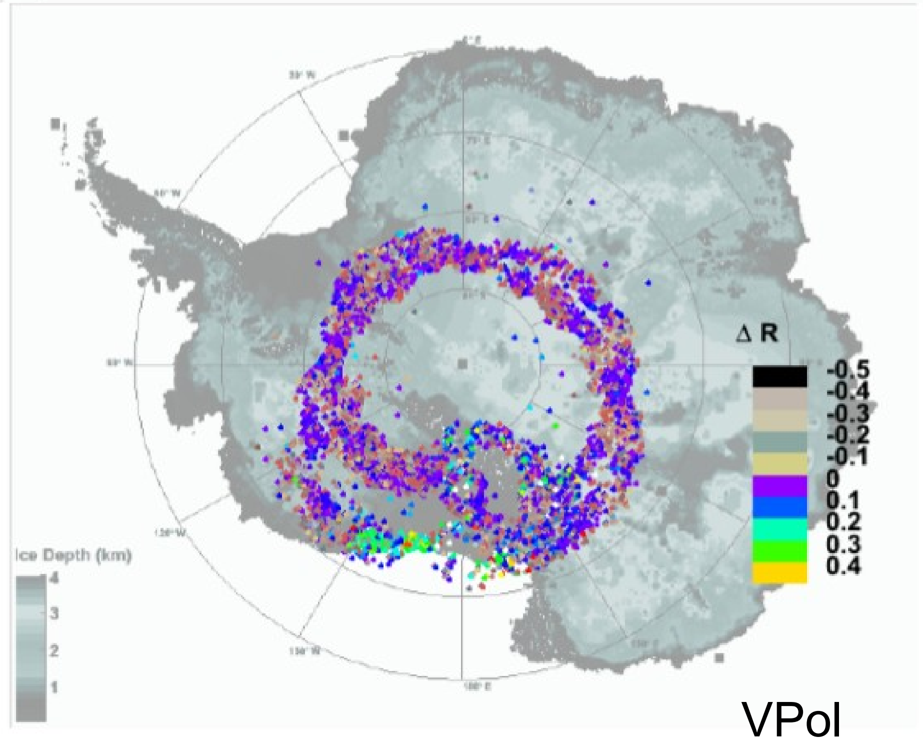


ANITA Solar Ratio Results

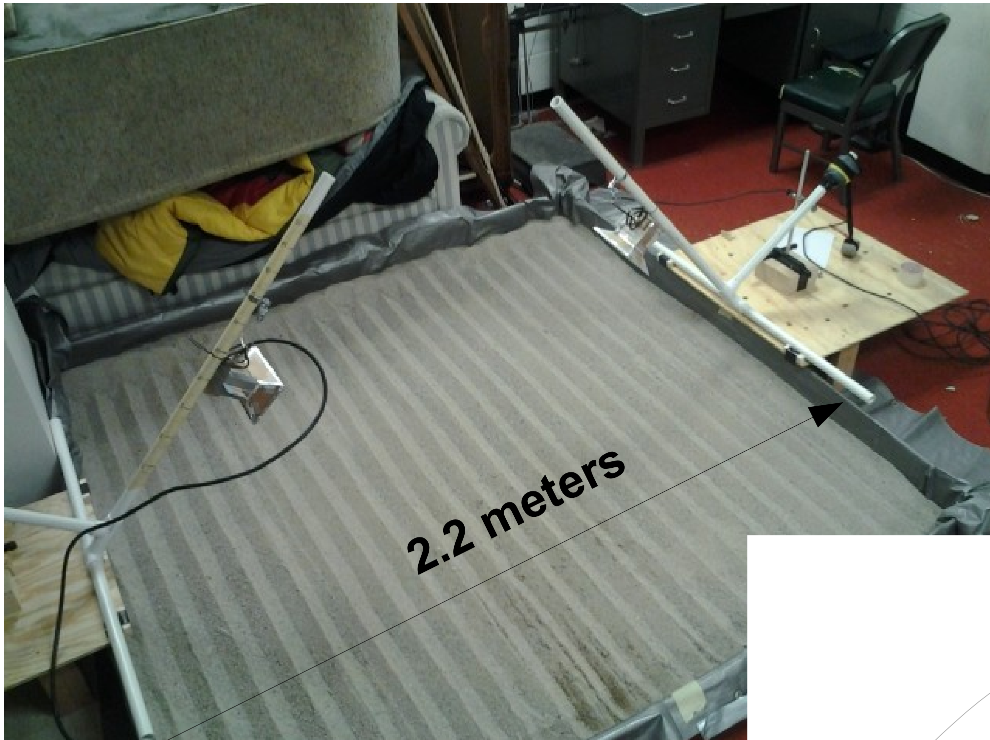




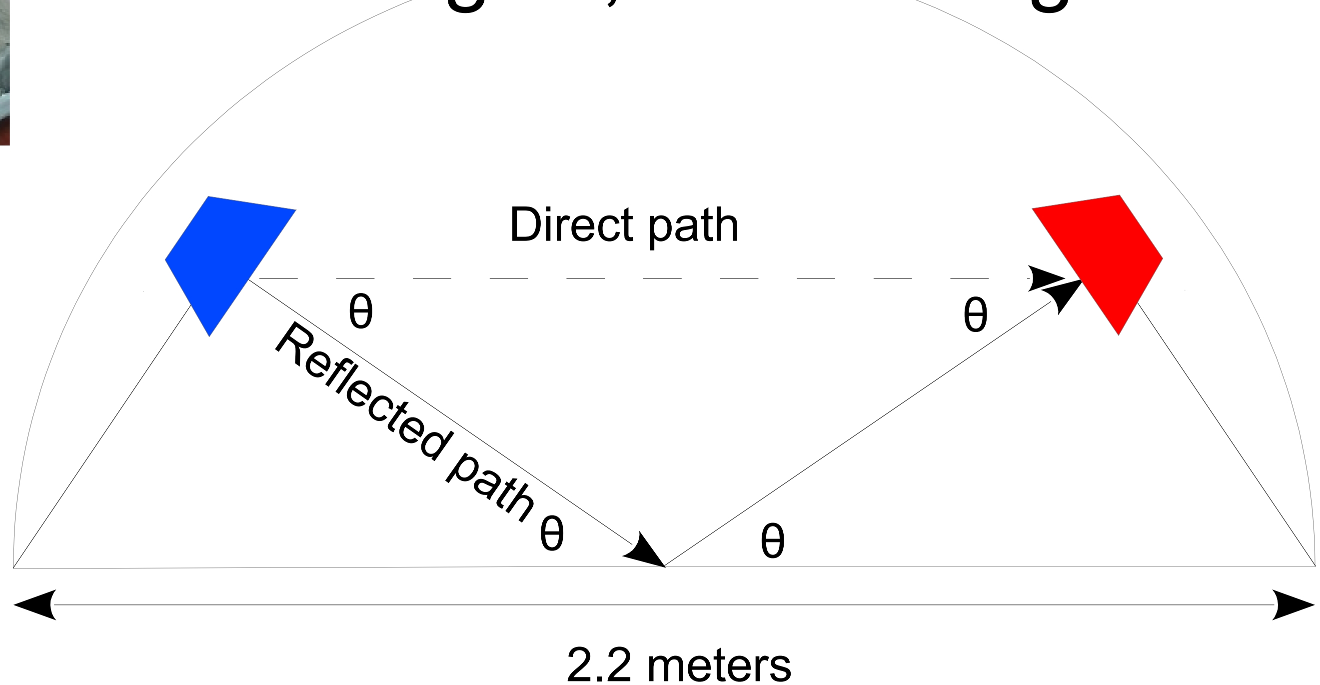




In-lab experimental set-up

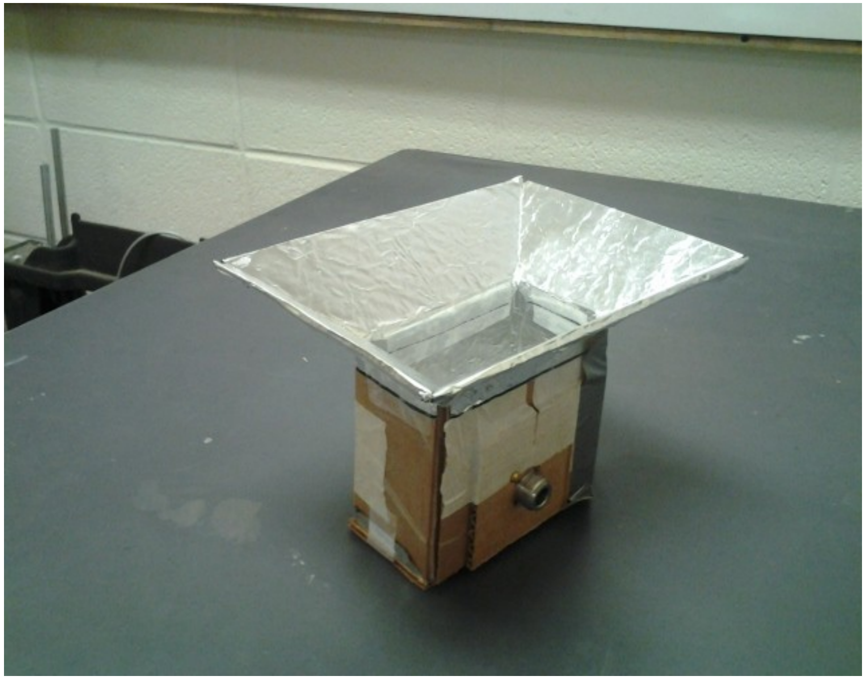


- Box size determined by Fresnel zones, 1st and 2nd
- Antenna beams pointed toward center of box at all angles, 5 to 35 degrees



- Need to account for interference between direct and reflected paths to extract reflected power

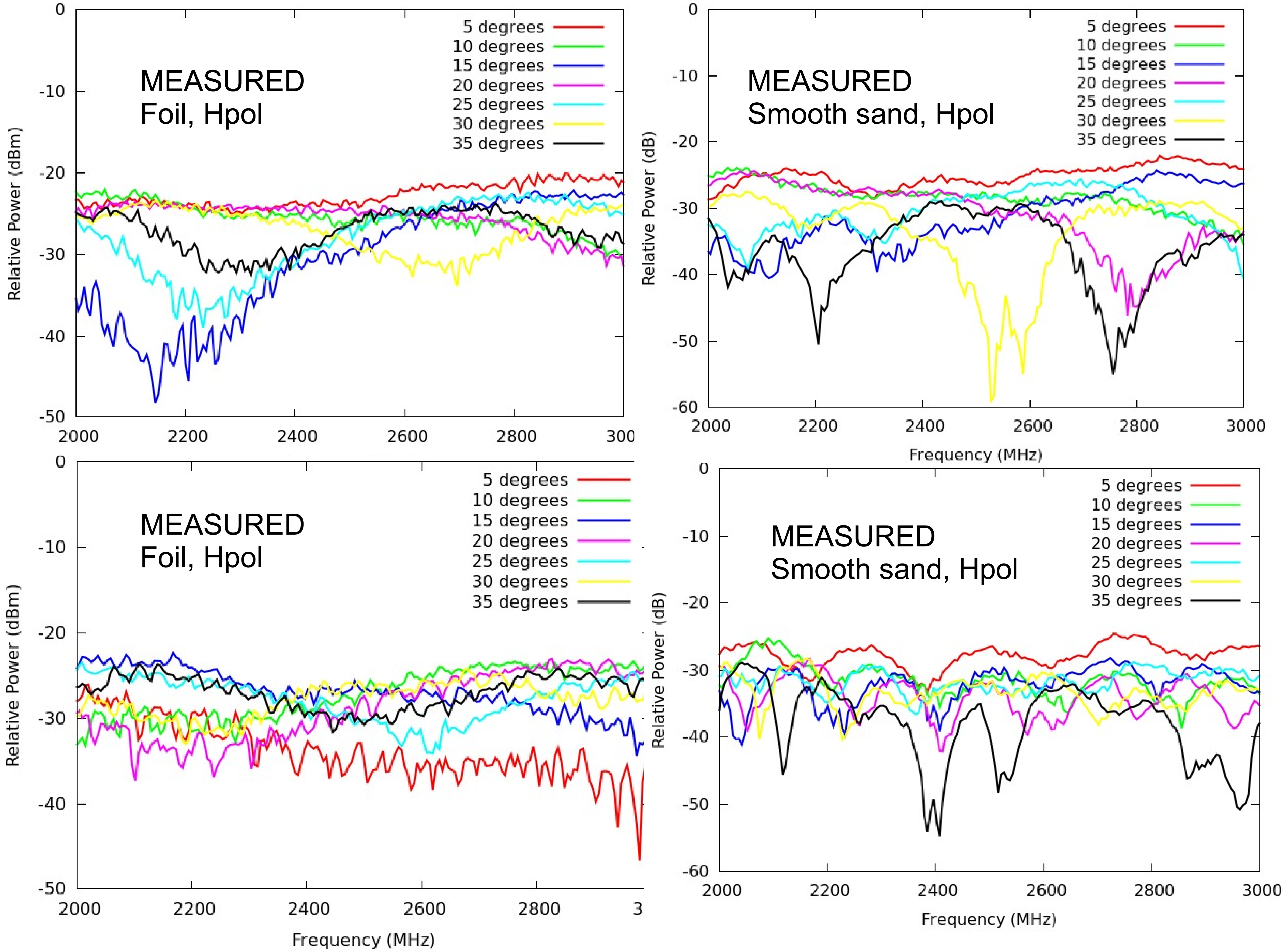
Horn Antennas



- Beam is best from 2-3GHz (15-10cm), ~ 8dB forward gain
- ANITA range is 0.2-1.2 GHz (150 cm – 25 cm)

Surfaces

- Smooth surface
  - Aluminum foil – ~~removes reflection coefficient as a function of incidence angle,~~ specular reflection
  - Sand – measure refractive index w/ fit to Fresnel curve, diffuse reflection
- Rough Surfaces
  - Sawtooth patterns with varying height, z_pk-pk, and wavelength, λ
  - Ridges transverse to antenna beam direction
  - Use λ above, within, and below the 10 – 15 cm range, see where decoherence effects cut in and out



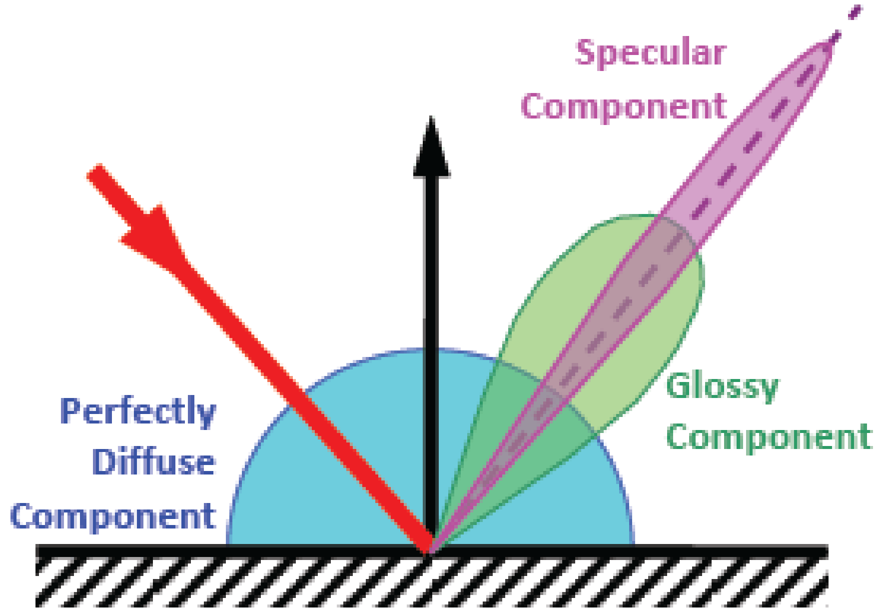
MEASURED
Foil, Hpol
Relative Power (dBm)
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
0
-10
-20
-30
-40
-50
2000
2200
2400
2600
2800
300
MEASURED
Smooth sand, Hpol
Relative Power (dB)
Frequency (MHz)
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
0
-10
-20
-30
-40
-50
-60
2000
2200
2400
2600
2800
3000
MEASURED
Foil, Hpol
Relative Power (dBm)
Frequency (MHz)
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
0
-10
-20
-30
-40
-50
2000
2200
2400
2600
2800
3
MEASURED
Smooth sand, Hpol
Relative Power (dB)
Frequency (MHz)
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
0
-10
-20
-30
-40
-50
-60
2000
2200
2400
2600
2800
3000

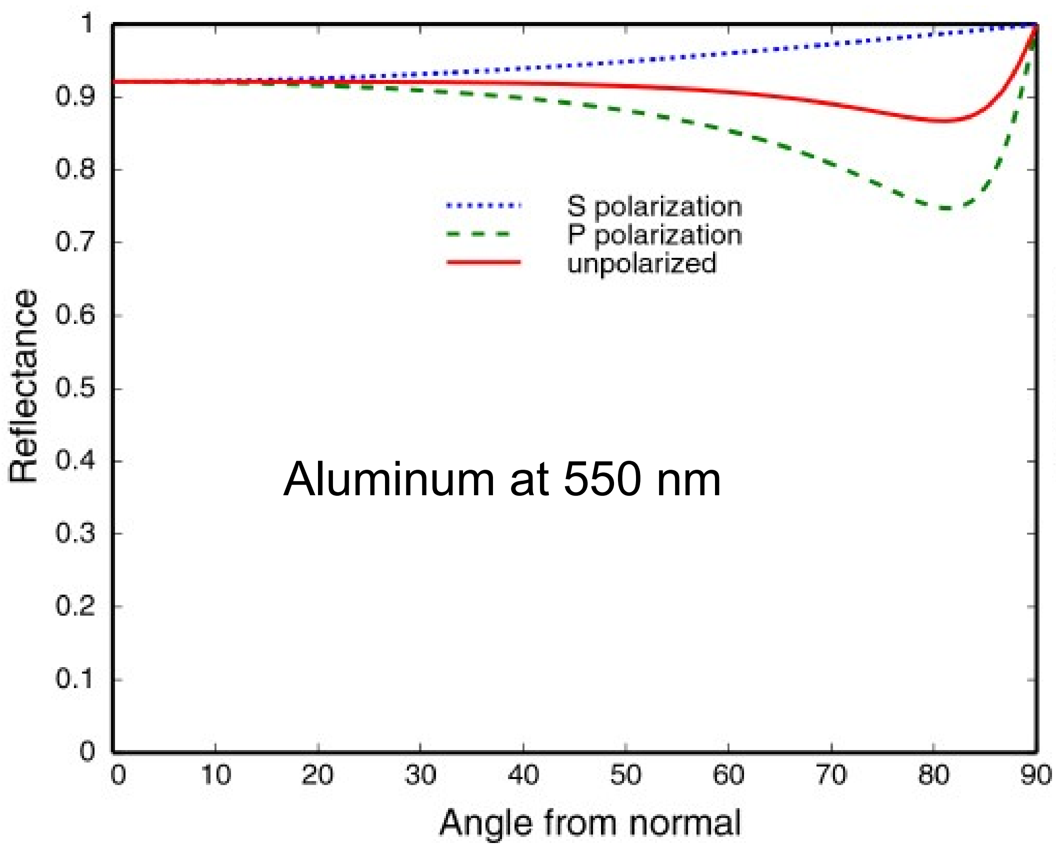
Measurements and Processing

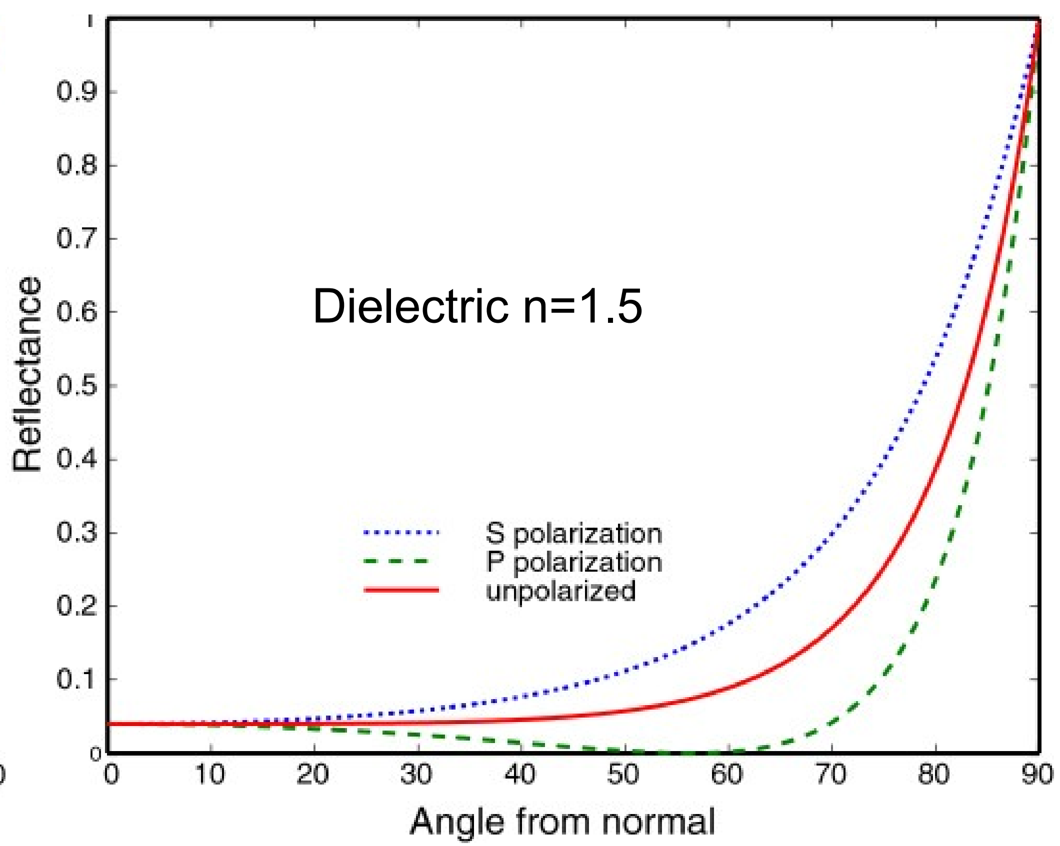
- Data recorded with network analyzer, measures relative power, L_{dB} in dBm
- Gain measurements (beam pattern) taken in free-space
- Use Friis transmission equation to apply gain and free-space loss

Modelling

- Using only specular spike for conductor
- only diffuse component for dielectric



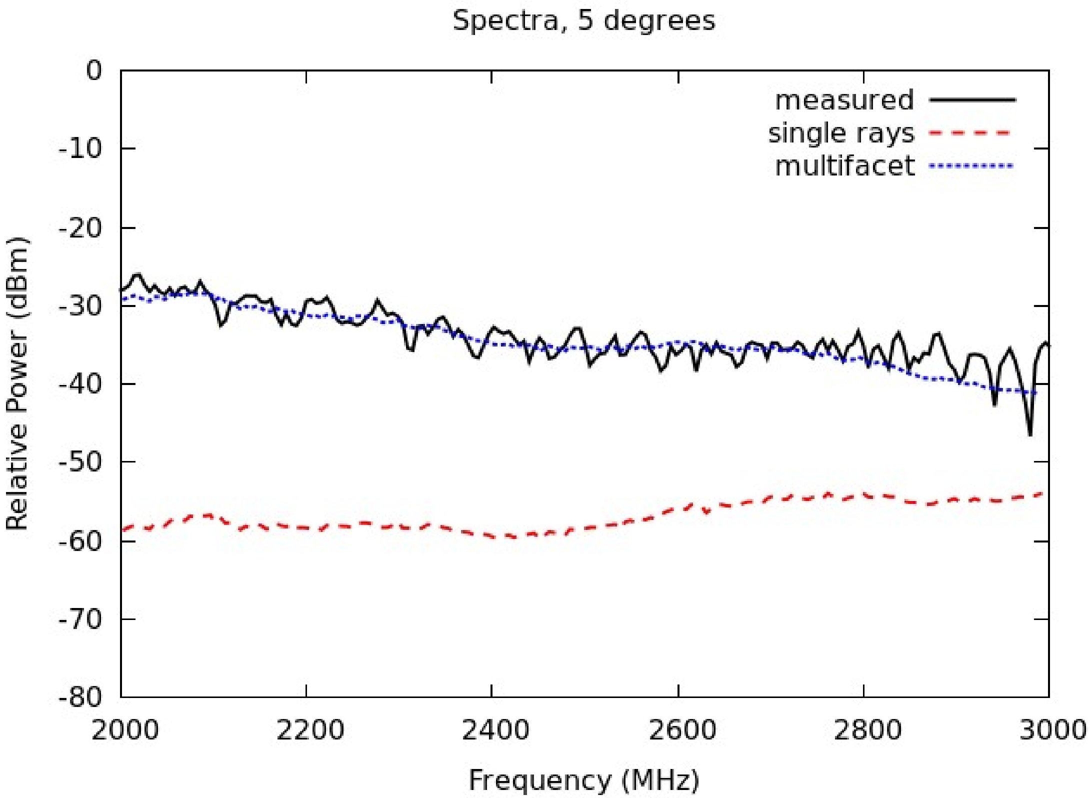


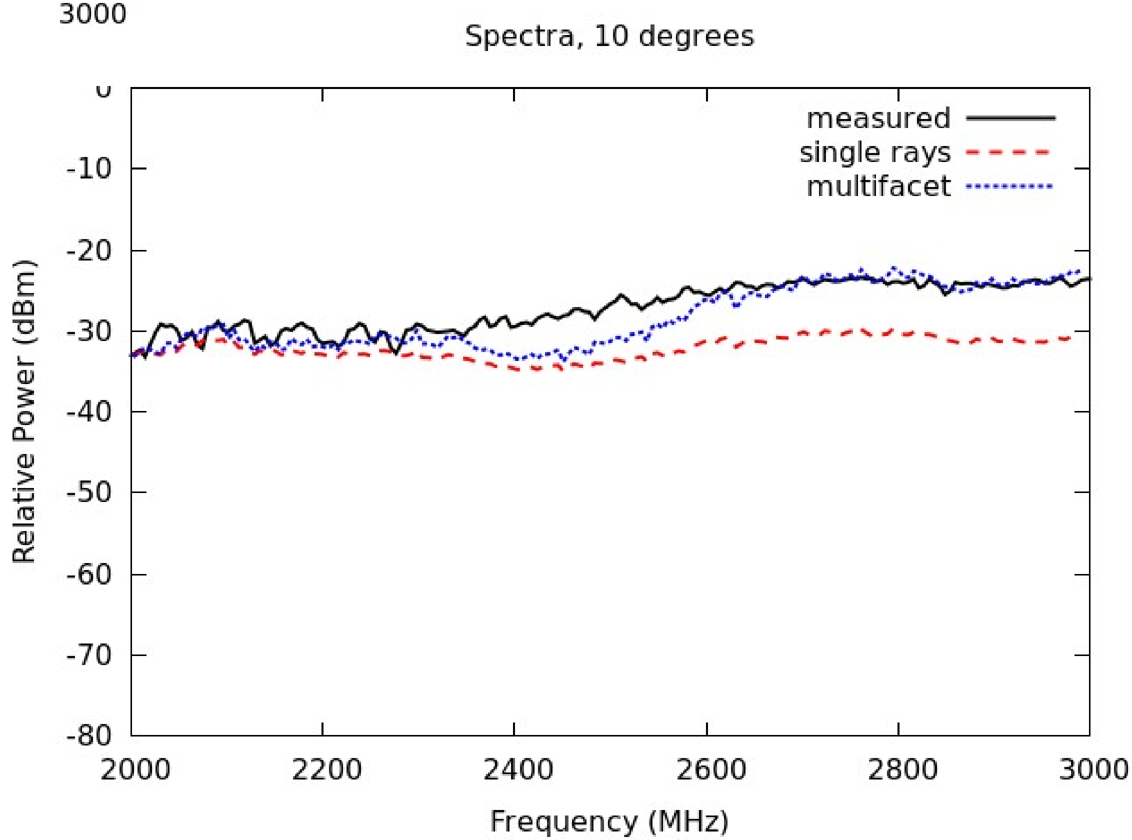


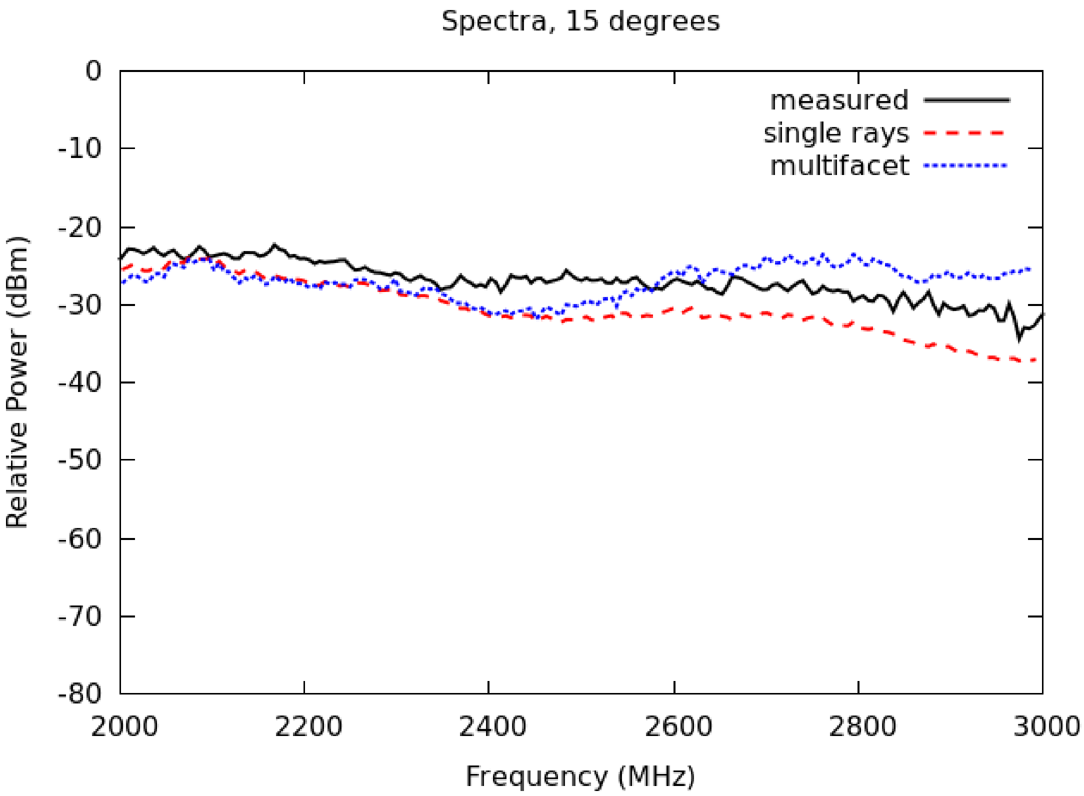
Modelling

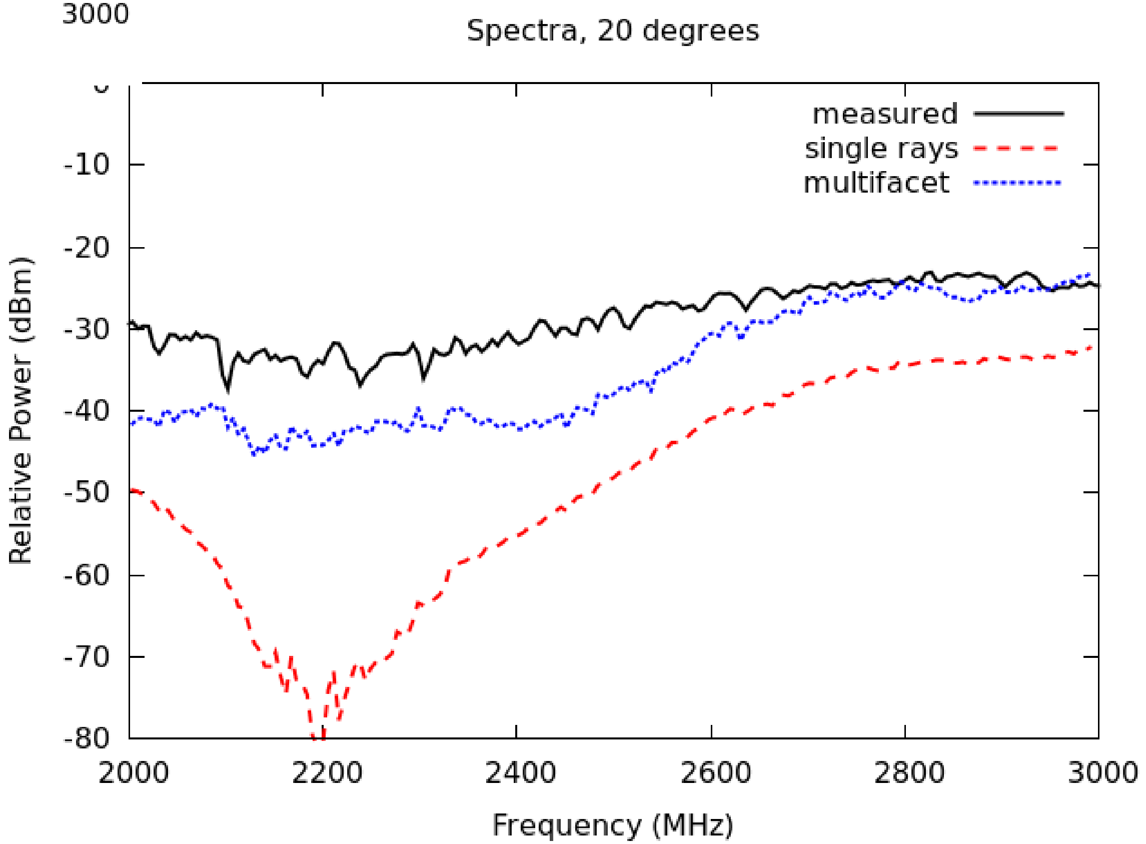
- Determine direct component based on free space measurements
- Scan over all surface facets
- Assess sensitivity of result to changing each reflection component, width of specular spike, Fresnel magnitude

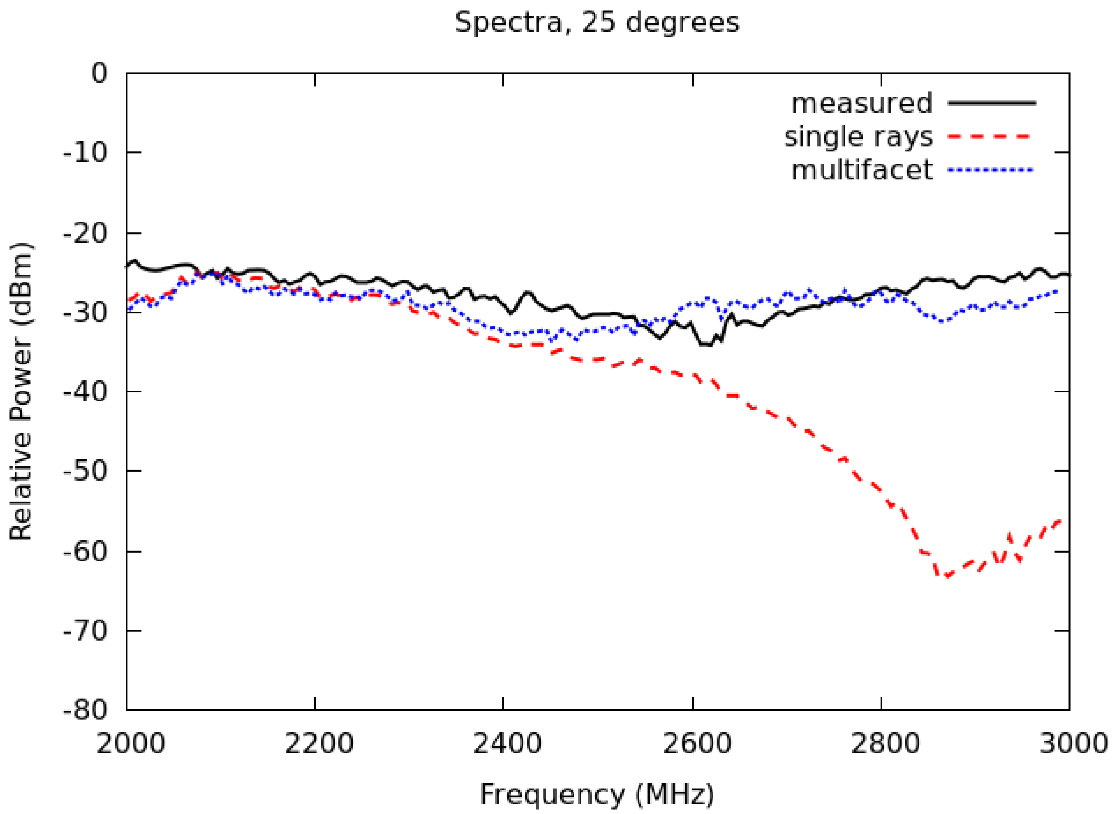
Measured vs modeled
Flat foil
Vpol
5 – 35 degree elevation angle
2 degree specular spike width



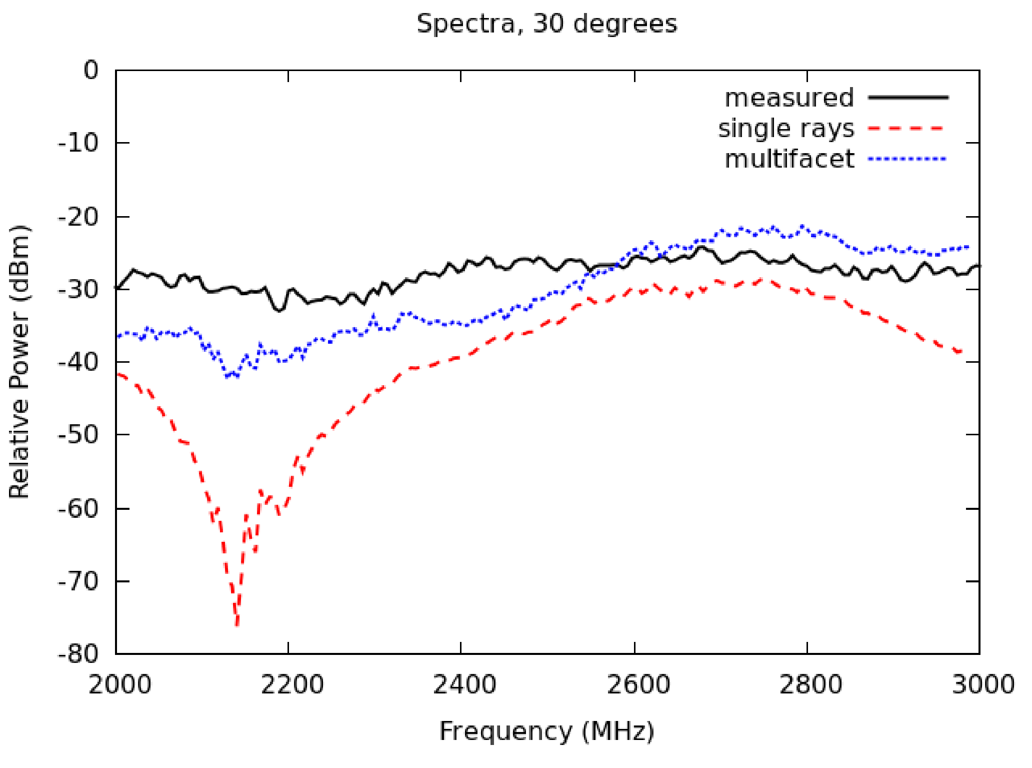



Spectra, 15 degrees
measured
single rays
multifacet
Relative Power (dBm)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
2000
2200
2400
2600
2800
3000


Spectra, 20 degrees
measured
single rays
multifacet
Relative Power (dBm)
Frequency (MHz)
-10
-20
-30
-40
-50
-60
-70
-80
2000
2200
2400
2600
2800
3000



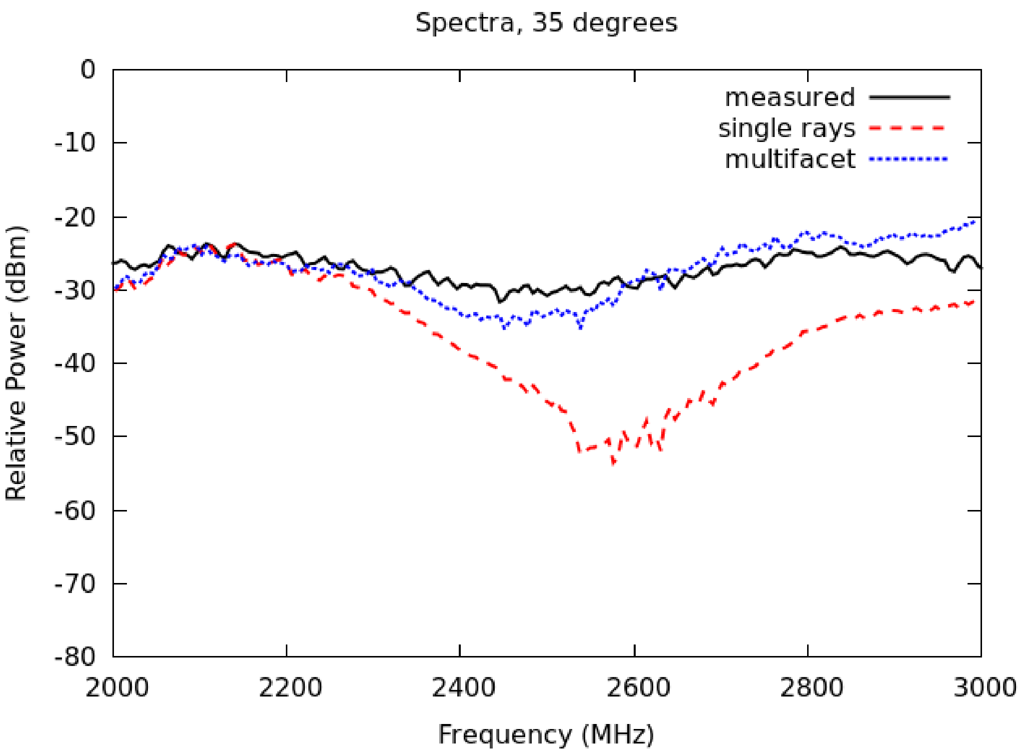
Spectra, 25 degrees
measured
single rays
multifacet
Relative Power (dBm)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
2000
2200
2400
2600
2800
3000



Spectra, 30 degrees
measured
single rays
multifacet
Relative Power (dBm)
Frequency (MHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
2000
2200
2400
2600
2800
3000

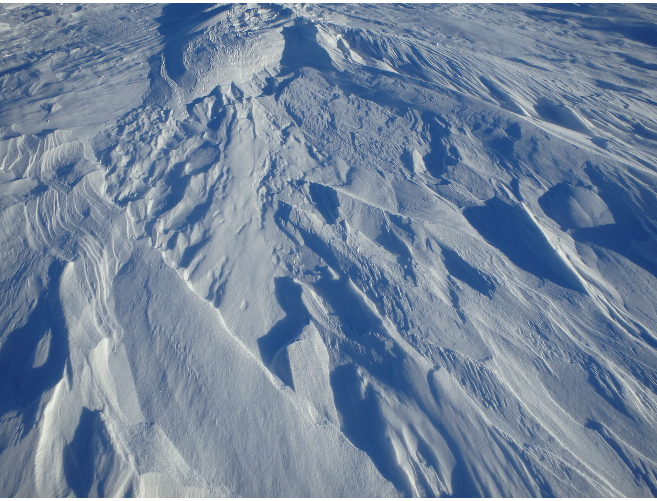
Modelling Summary

- Fresnel component for foil makes elevation angle accuracy more important
- Vpol foil results are decent with only specular spike, Hpol are not as consistent
- Dielectric surfaces will require both specular and diffuse components

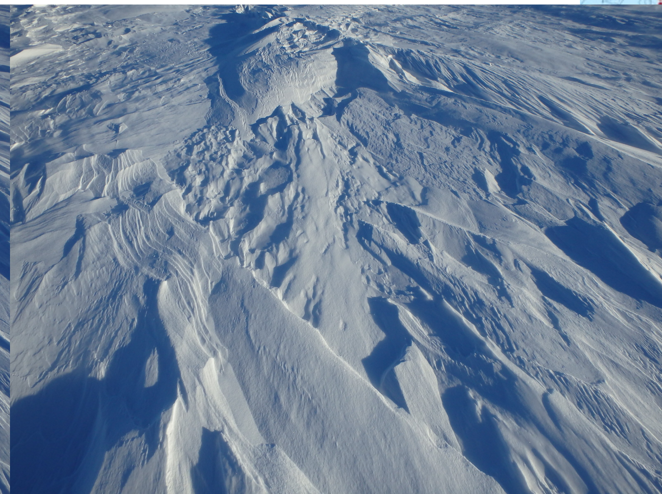


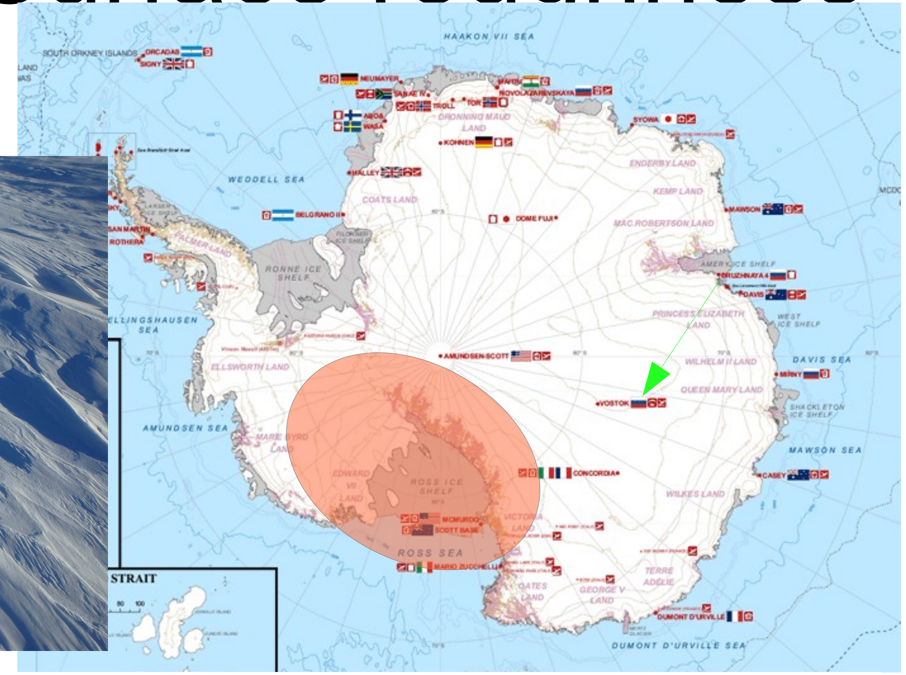
Stereoscopic imaging ->Surface roughness

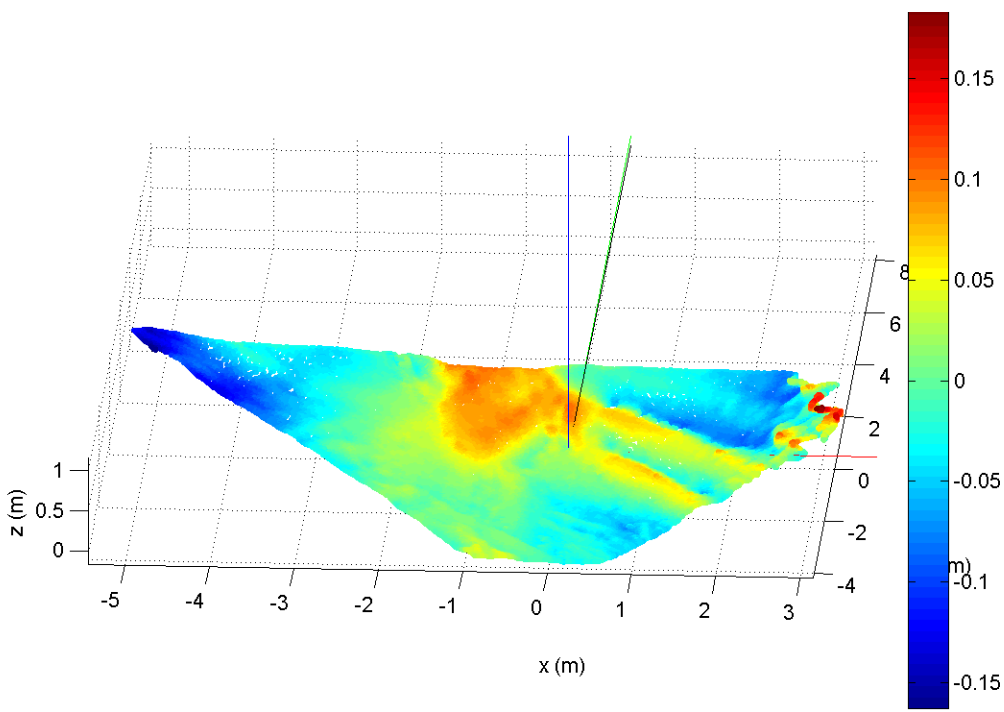
Left image

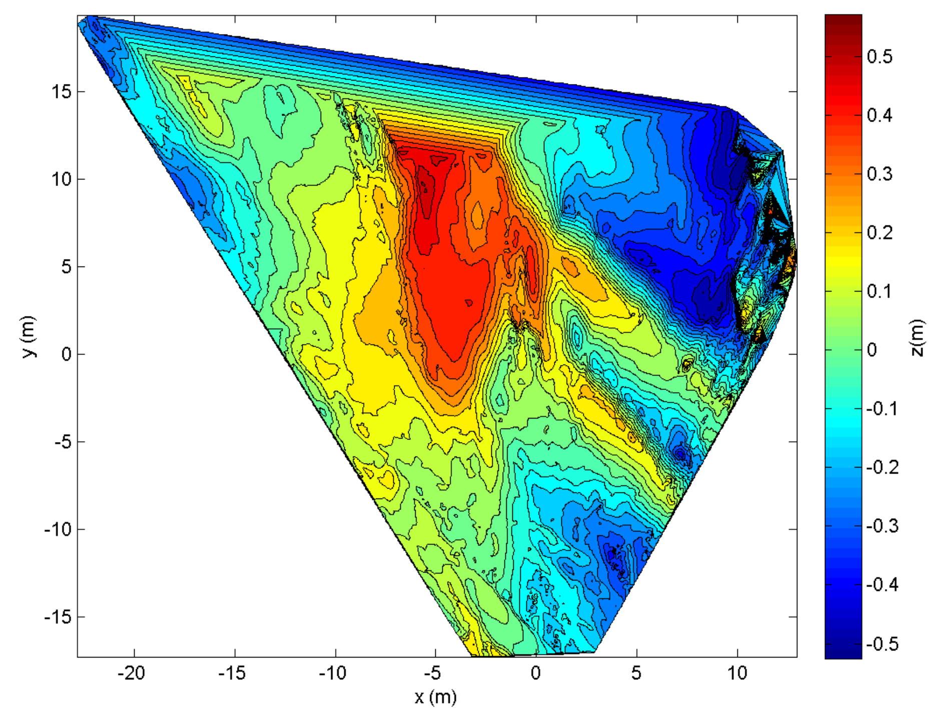


Right image









The future

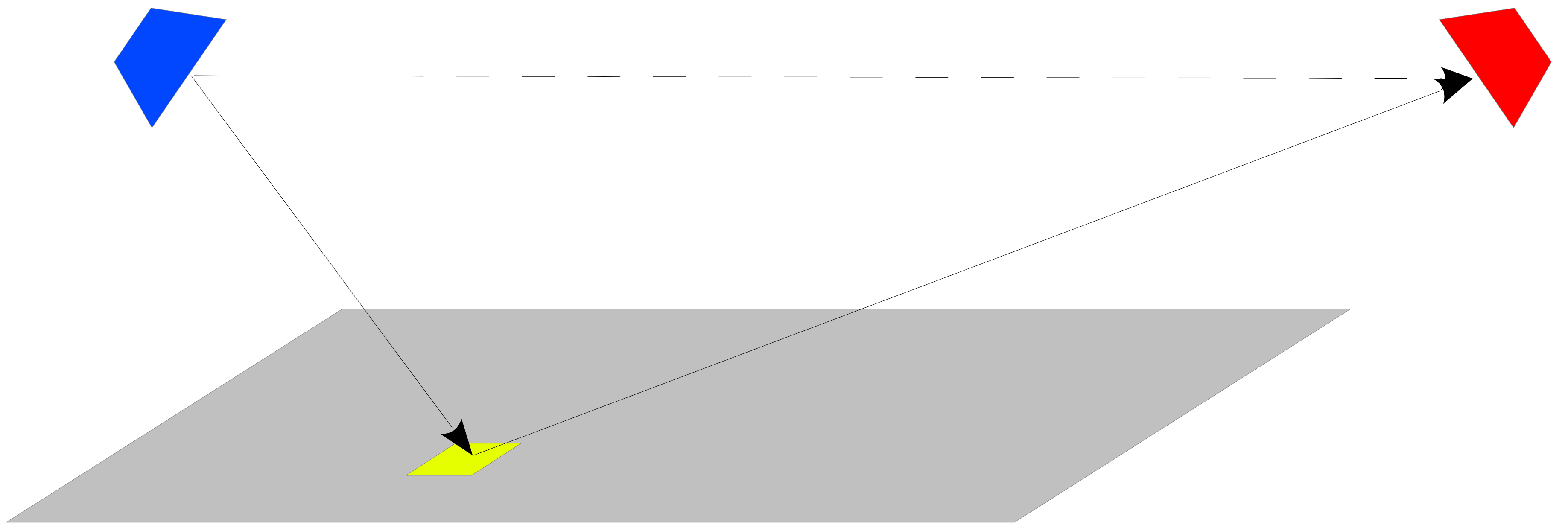
- Using foil and various sand depths, determine content of surface vs volume reflections
- Determine roughness parameters from stereoscopic images
- Assess correlations of backscatter and wind data

*work supported by NSF0064451

References

1. Courtesy of Frederique Remy, Remote Sensing 2009, 1, 1212-1239; doi:10.3390/rs1041212
2. Virial International http://www.virial.com/reflection-models.html
3. Fresnel Reflectance http://www.graphics.cornell.edu/~westin/misc/fresnel.h

CreSIS Google Images



$$L_{dB} = 10\log\left(\frac{P}{P_0}\right)$$

$$2G_\theta = \frac{P}{P_0}\left(\frac{4\pi R}{\lambda}\right)^2$$

$$\frac{A_D}{A_0} = (\cos\phi_D + i\sin\phi_D)\sqrt{2G_D}\left(\frac{\lambda}{4\pi R}\right)$$

$$\phi_D = \frac{2\pi R_D}{\lambda}$$

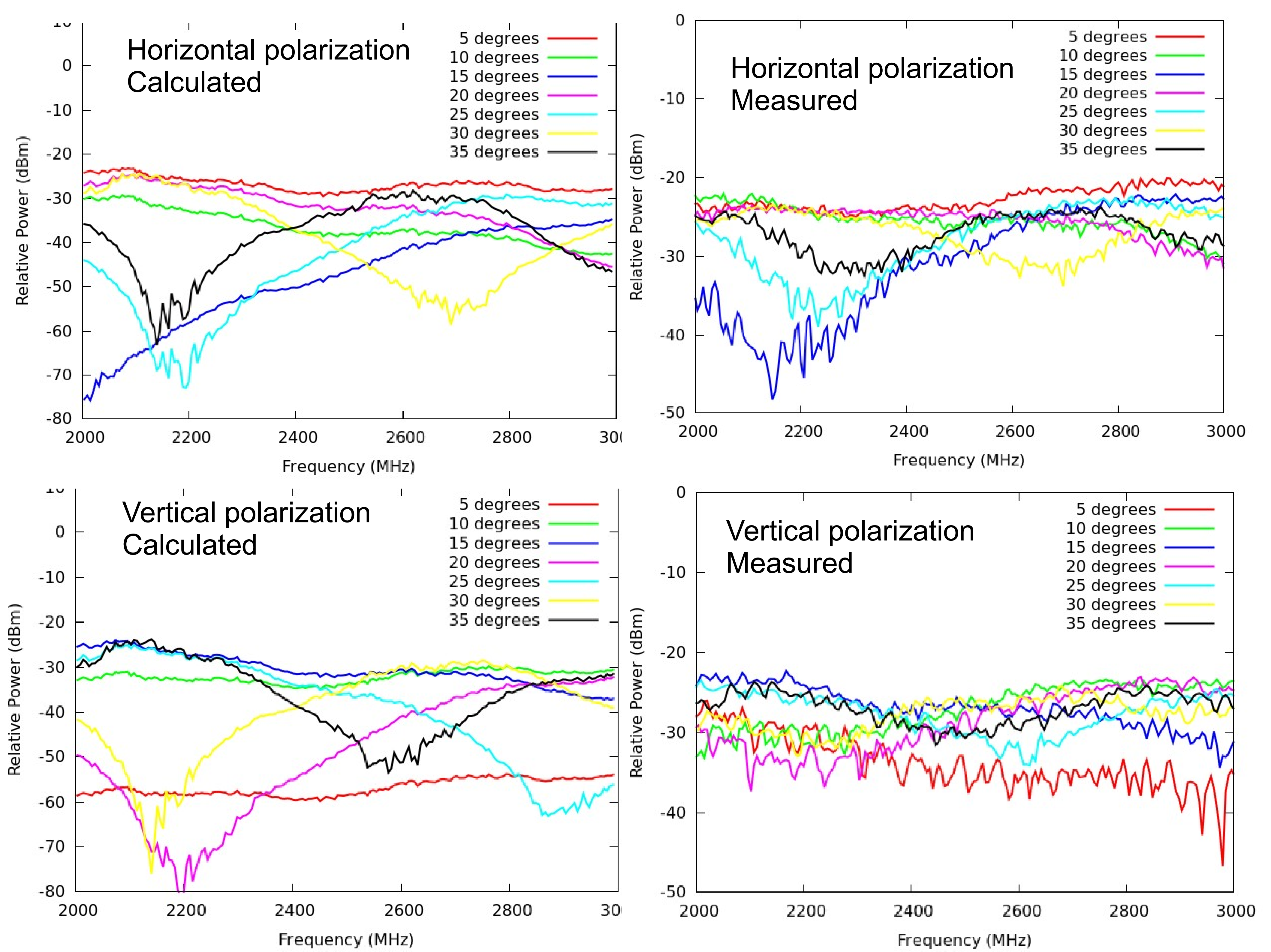
$$\frac{P}{P_0} = \left|\frac{A}{A_0}\right|^2 = \left|\frac{A_D + A_R}{A_0}\right|^2$$

Issues

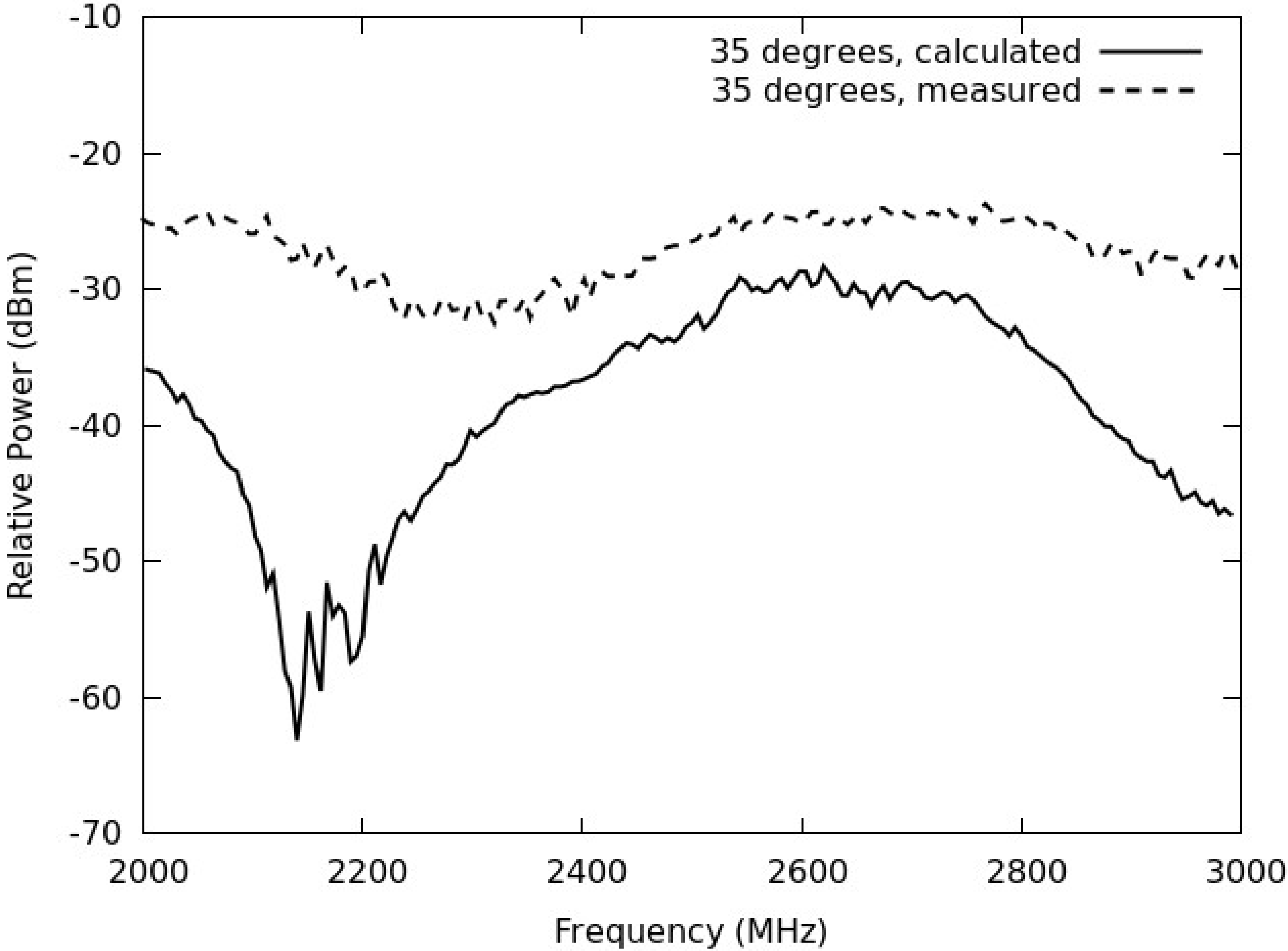
- Insufficient data on roughness in the cm-m scale – currently using Radarsat data
- ANITA solar data not frequency dependent, spans entire 200-1200MHz range
- Solar signal is dominant in 200-400 MHz band

Current roughness accounting

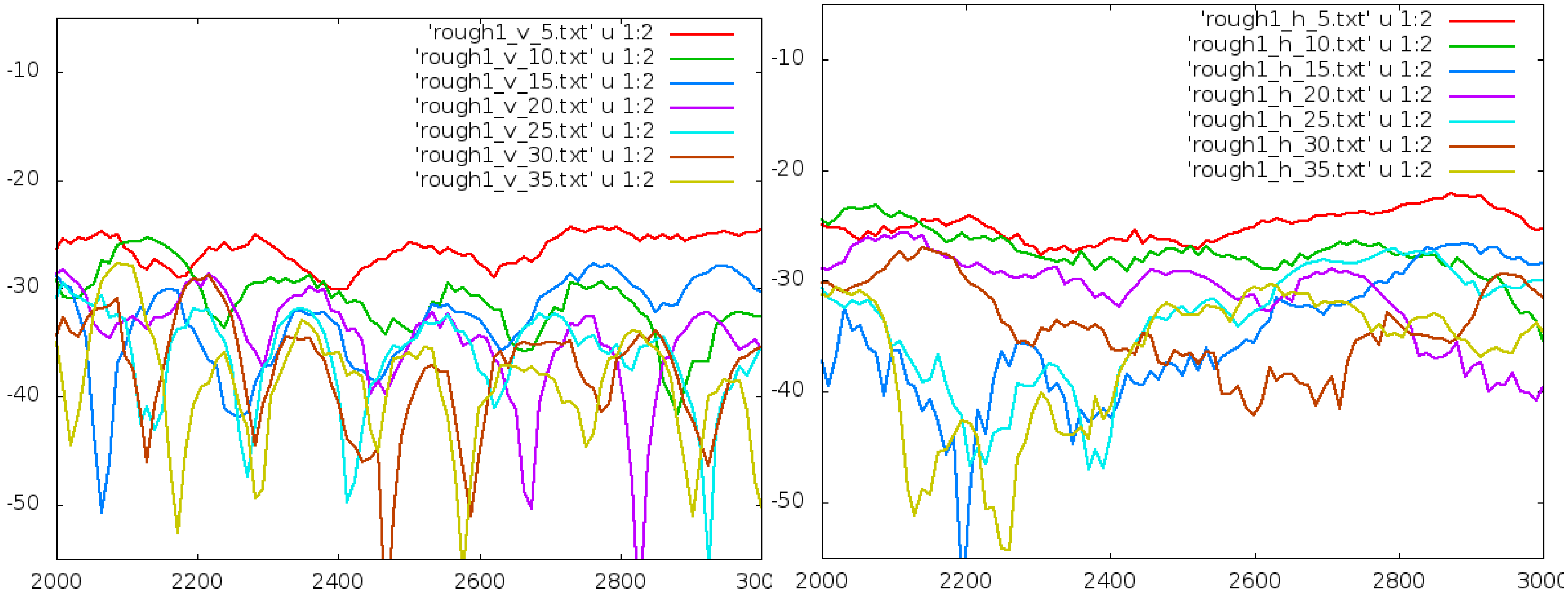
- Self-affine fractal surfaces, Huygen-Fresnel integrals, conservative
  - Uses parameters based on surface rms height
  - Accounts for variation of rms height based length of profile
- Most recent energy reconstructions uses intermediate values between conservative and smooth


Horizontal polarization
Calculated
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
Relative Power (dBm)
0
-10
-20
-30
-40
-50
-60
-70
-80
2000
2200
2400
2600
2800
Frequency (MHz)
Horizontal polarization
Measured
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
Relative Power (dBm)
0
-10
-20
-30
-40
-50
2000
2200
2400
2600
2800
3000
Frequency (MHz)
Vertical polarization
Calculated
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
Relative Power (dBm)
0
-10
-20
-30
-40
-50
-60
-70
-80
2000
2200
2400
2600
2800
Frequency (MHz)
Vertical polarization
Measured
5 degrees
10 degrees
15 degrees
20 degrees
25 degrees
30 degrees
35 degrees
Relative Power (dBm)
0
-10
-20
-30
-40
-50
2000
2200
2400
2600
2800
3000
Frequency (MHz)

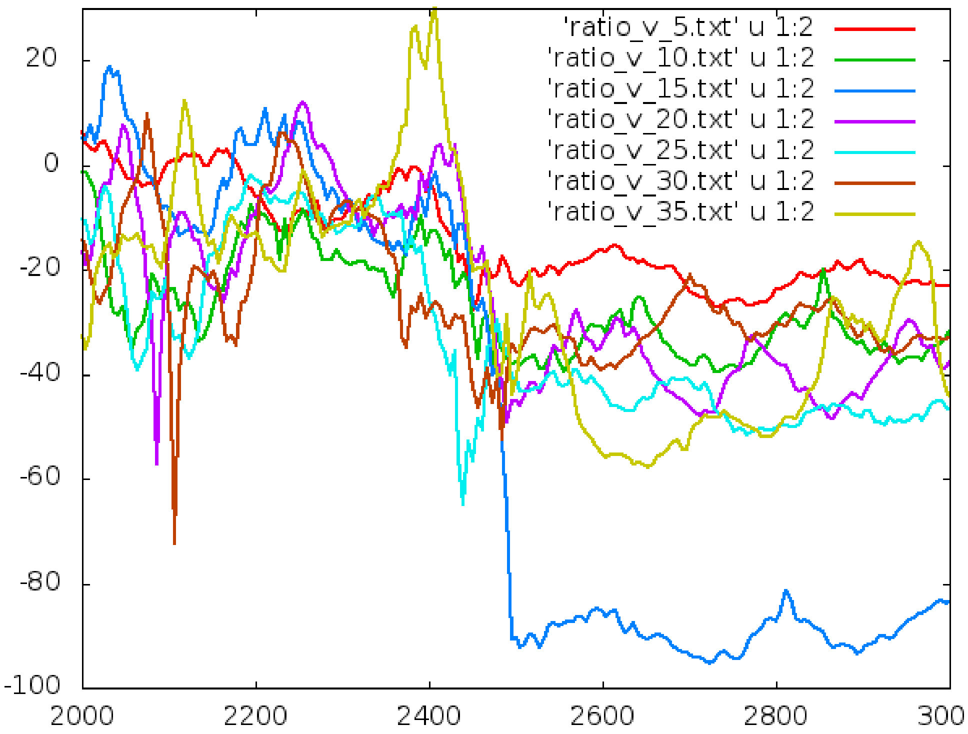
Calculated vs measured, flat aluminum foil

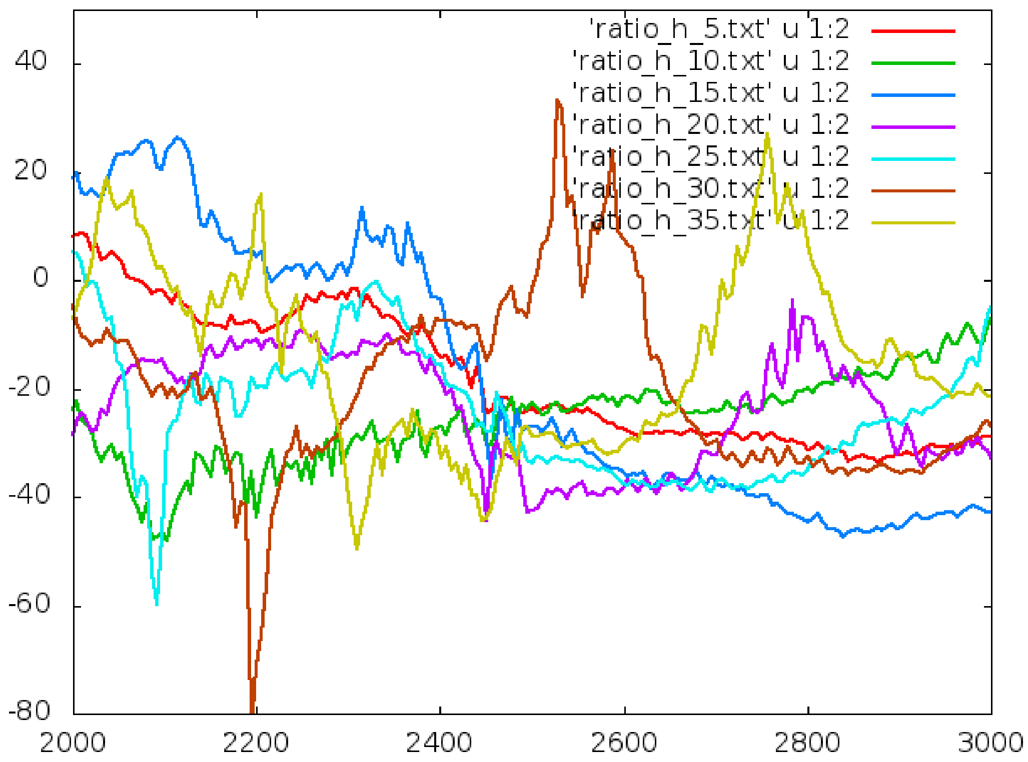


Rough1 – z_pk-pk=6 cm, λ = 14 cm

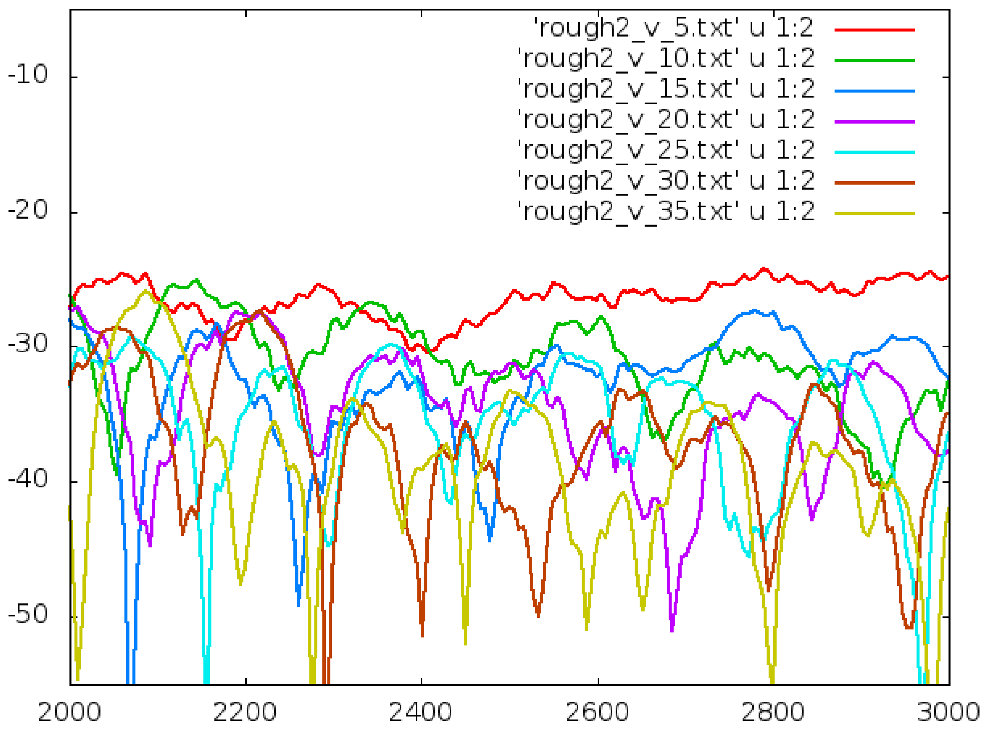


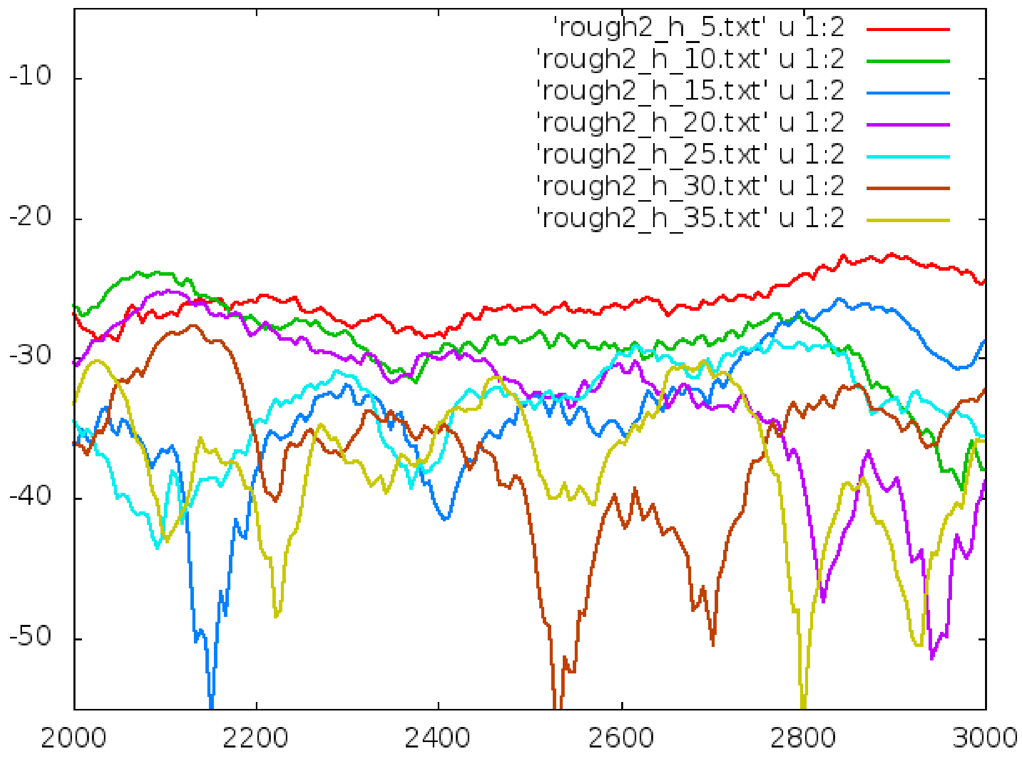
Rough1:smooth



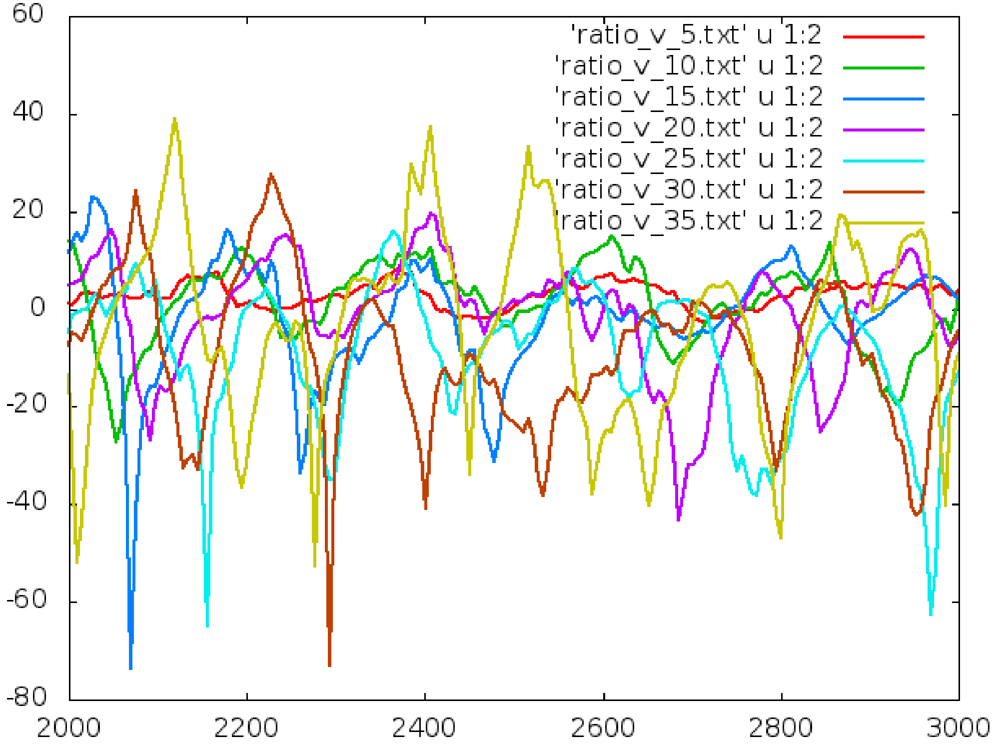


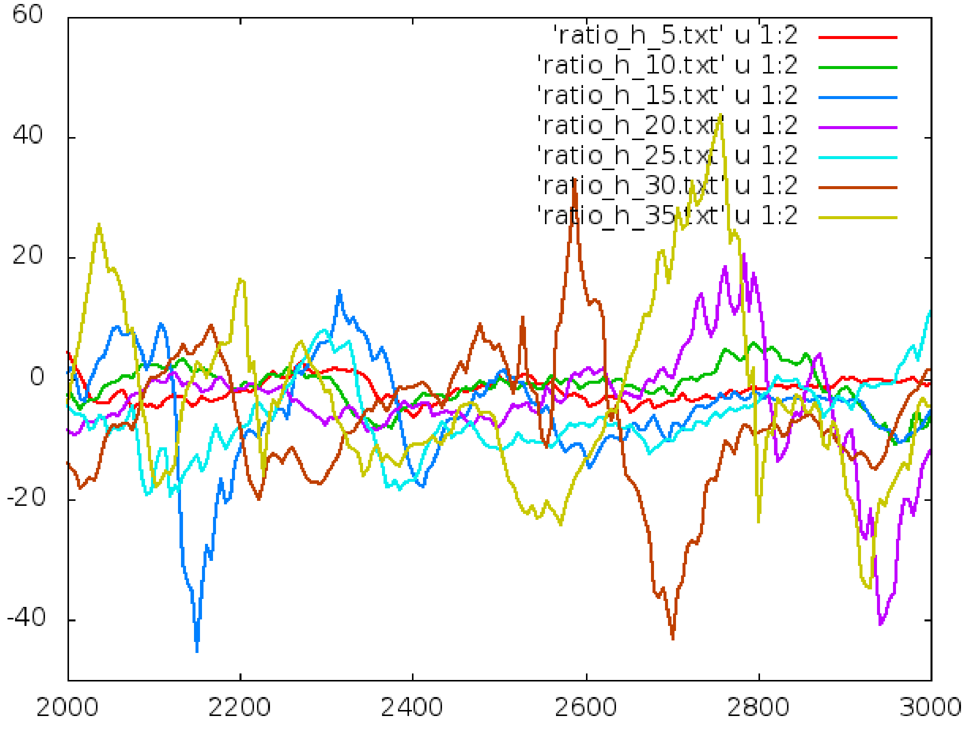
Rough2 – z_pk-pk=6 cm, λ = 18 cm





Rough2:smooth





Rough3 – z_pk-pk=4 cm, λ = 10 cm

Roadmap

- **Cosmic rays (CRs) and neutrinos** are interesting, especially the ultra-high energy (UHE) ones
- **RF pulses develop in the particle showers** produced when UHE particles collide in the atmosphere and ice
- **Frequency spectrum of RF pulses** are used for event reconstruction
- ANITA is looking for in-ice neutrinos events and **has observed reflected CR events**
- Most of the CR events were **reflected from the ice interface**
- Any observed neutrino events would be **transmitted through the ice interface**

Abstract

- For radio antenna detectors located in or above the Antarctic ice sheet, the reconstruction of both ultra-high energy (UHE) neutrino and cosmic ray air shower events requires understanding the transmission and reflection properties of the air-ice interface. To this end, surface and volume scattering from granular materials in the microwave frequency range are measured and stereoscopic images of the ice surface, obtained by the Antarctric Geophysics Along the Vostok Expedition (AGAVE), are used to determine the 3D surface structure. This data is implemented to