Ray tracing in ARA and ARIANNA

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The Askaryan Radio Array (ARA) and The Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA)

- The Askaryan Radio Array (ARA) consists of radio antennas placed 200 m below the surface of ice at the South Pole.
- The Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA) detects neutrinos at the surface that are reflected off of the ice-sea boundary at Moore's bay.
- Both use the Askaryan effect to detect neutrinos.

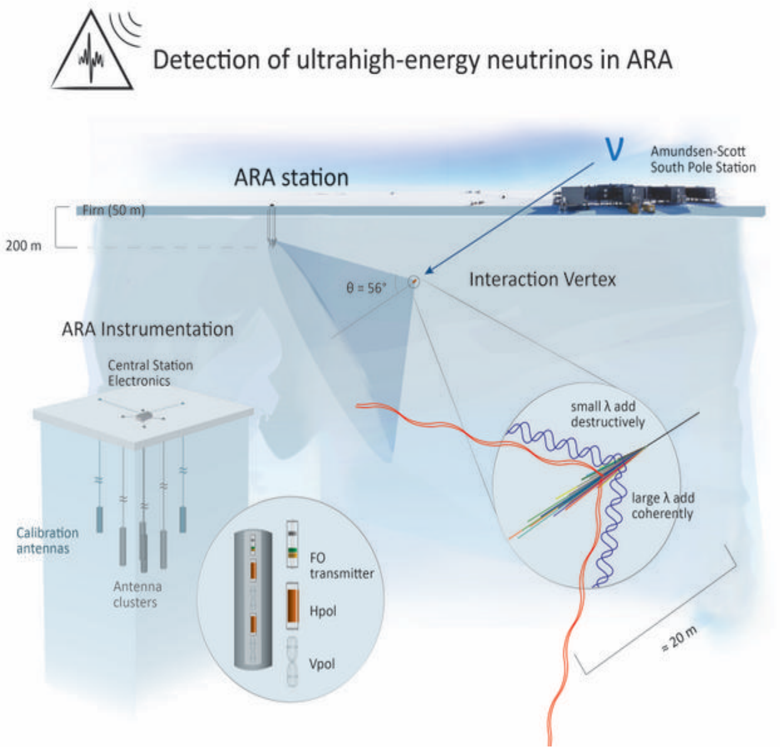
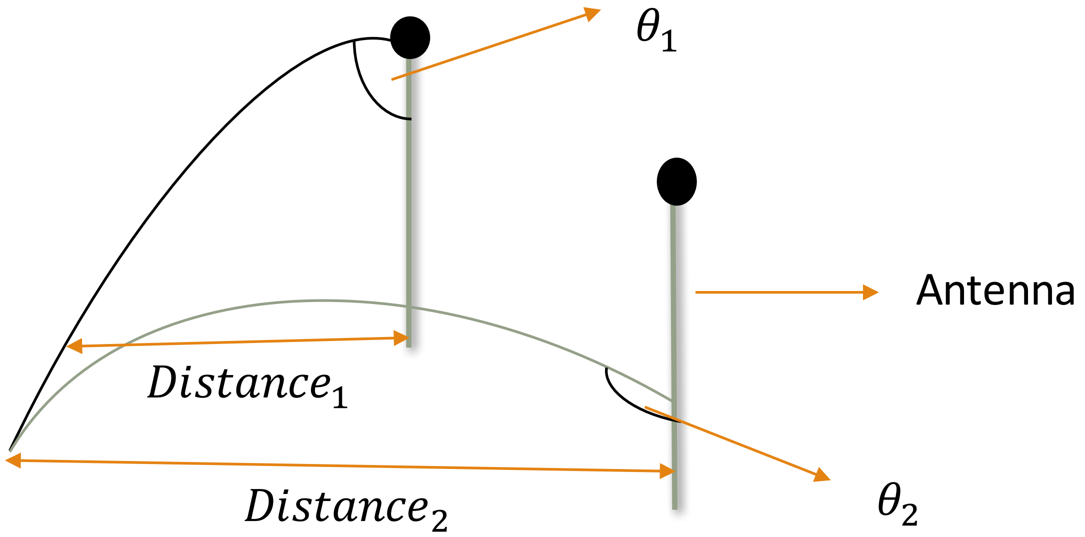


Fig.1. Detection of UHE neutrinos in ARA

Why study ray propagation?

- Determination of optimal position of detectors to capture radio signals.
- Determination of angles at which signals hit the antenna.

  Effectiveness of antennas in capturing signals depends on angle at which signals hit the antenna.
- Convenient way to calculate attenuation length at different locations of ice at the South Pole.
- Studying time delays between signals at different antennas which may lead to possible determination of background.



Modeling the index of refraction of ice versus the depth

- Modeling the index of refraction is an important step to solving ray propagation problems.
- Different models based directly on depth and ice density as a function of depth.

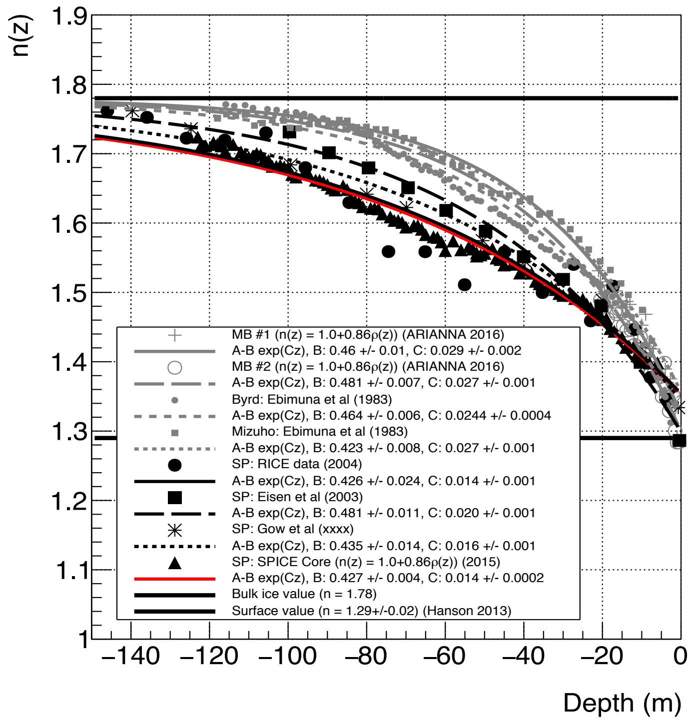


Fig. 2. Fits to the index of refraction of ice vs. its depth

Ray propagation

c_0= nc

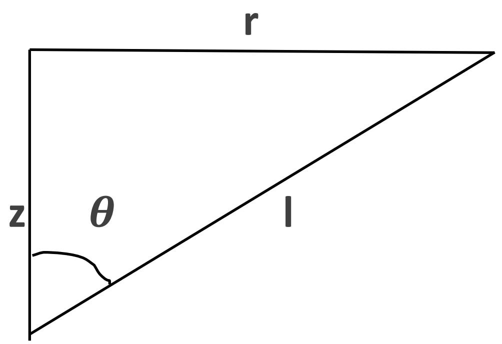
Assume α=nsinθ is constant (Snell's Law)

$$\frac{d\alpha}{dl} = 0 = \frac{dn}{dl} sin\theta + ncos\theta \frac{d\theta}{dl}$$

$$= \frac{dn}{dz} sin\theta . cos\theta + ncos\theta \ \frac{d\theta}{dl}$$

$$= cos\theta \left(\frac{dn}{dz} sin\theta + n \frac{d\theta}{dl}\right)$$

$$\Longrightarrow \ \frac{d\theta}{dz} = -tan\theta . \frac{1}{n} . \frac{dn}{dz}$$



Useful relations:

dz=cosθ.dl=cosθ.dt.$\frac{c_0}{n}$

dr=tan θ.dz

Ray propagation

1. $$\frac{d\theta}{dz} = -tan\theta.\frac{1}{n}.\frac{dn}{dz}$$

2. $$\frac{dr}{dz} = tan\theta$$

3. $$\frac{dt}{dz} = n.\frac{1}{c_0}.\frac{1}{cos\theta}$$

ARA ray propagation model results

- Dave Seckel (ARA): ray tracing by explicit solutions of differential equations.

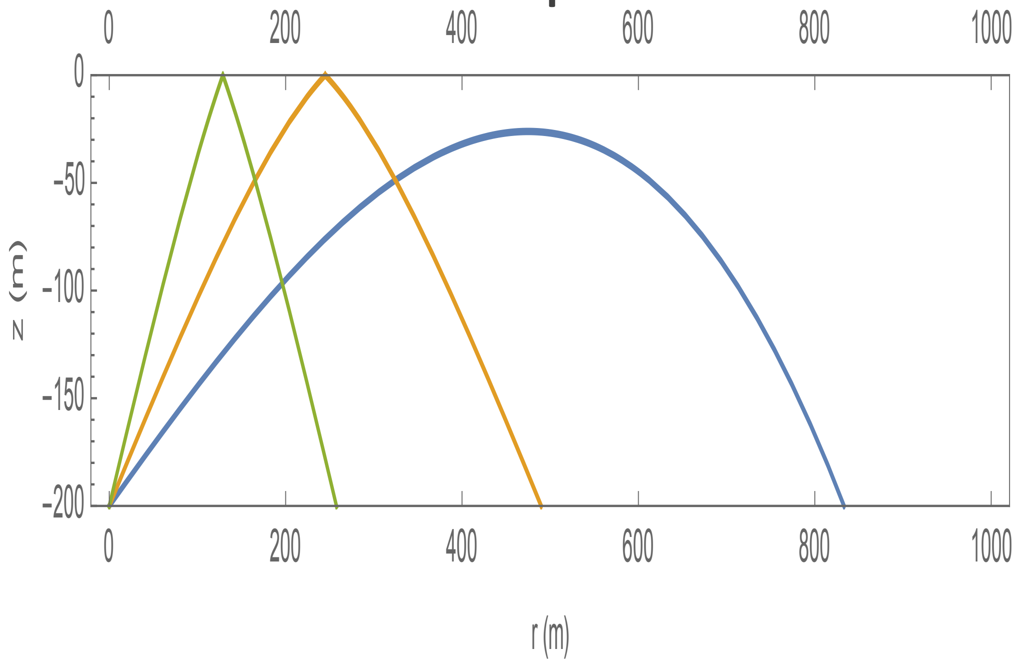


Fig. 3. Modeling of rays using Mathematica

Index of refraction of ice model used:

$$n(z)=1.78 - 0.43e^{0.0132z}$$

ARIANNA ray propagation model results

- Robert Lahmann (ARIANNA)

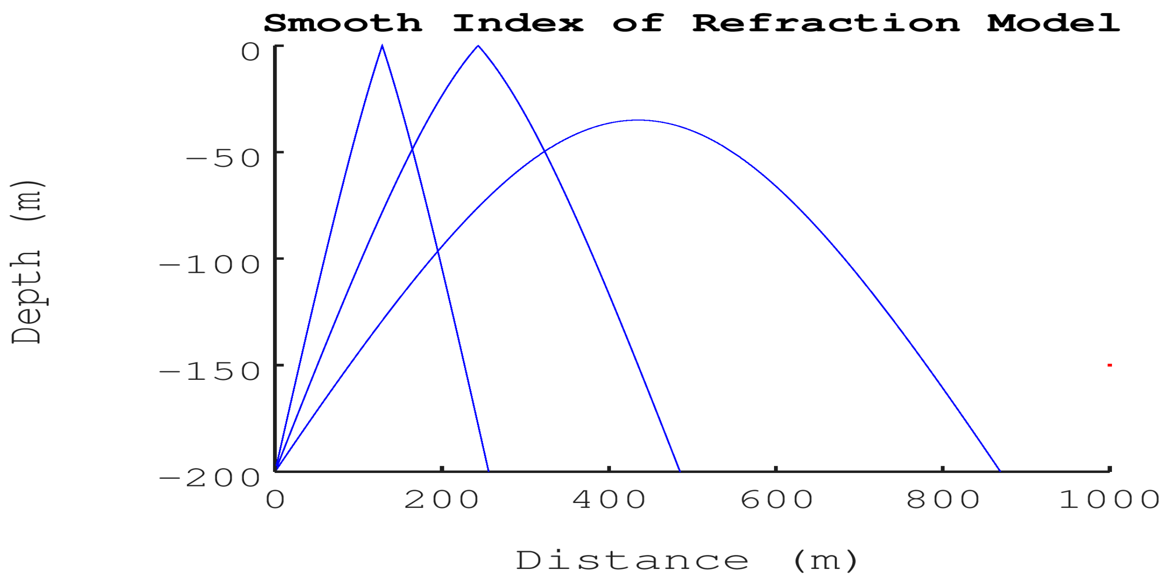


Fig. 4. Modelling of rays using Octave

Problems?

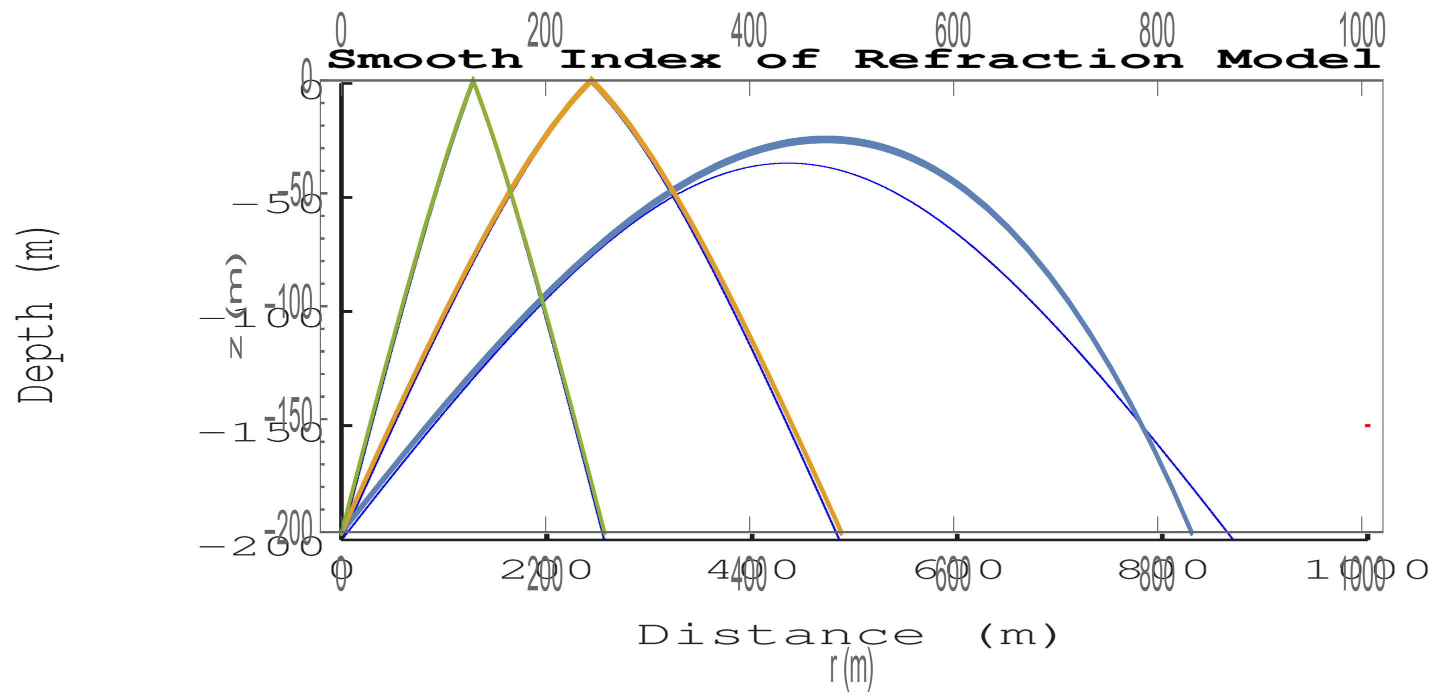


Fig. 5. Overlay of Mathematica and Octave graphs

Conclusion/further work

- Ray propagation is important in
- ❑ determining the optimal position of detectors to capture radio signals.
- ❑ angles at which signals hit the antenna which further help to improve the efficacy of antennas capturing radio signals.
- ❑ calculating attenuation length at different ice locations in Antarctica.
- ❑ studying time delays between signals at different antennas which may lead to possible determination of background.
- Further work in understanding the inconsistency in both the Mathematica and Octave code
- Be able to incorporate most appropriate ray propagation model into AraSim.