Environmental Acoustic Modeling of Rocket Noise to Determine Community Impacts

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Rocket Vehicle Types

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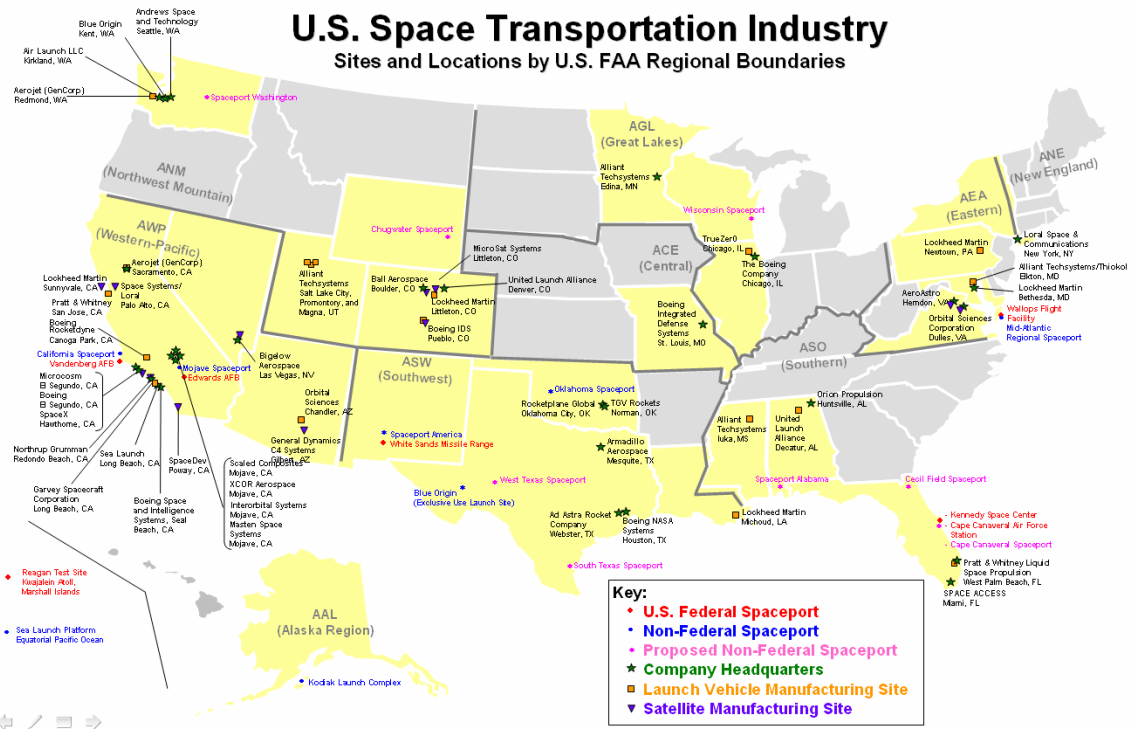
Environmental Review

- NEPA requires the consideration of environmental impacts and reasonable alternatives
- FAA regulations consider the acquisition of a launch site operator's license a Federal Action subject to environmental review
- Impacts from rocket noise are evaluated based on FAA Order 1050.1E, Change 1

Federal Aviation Administration

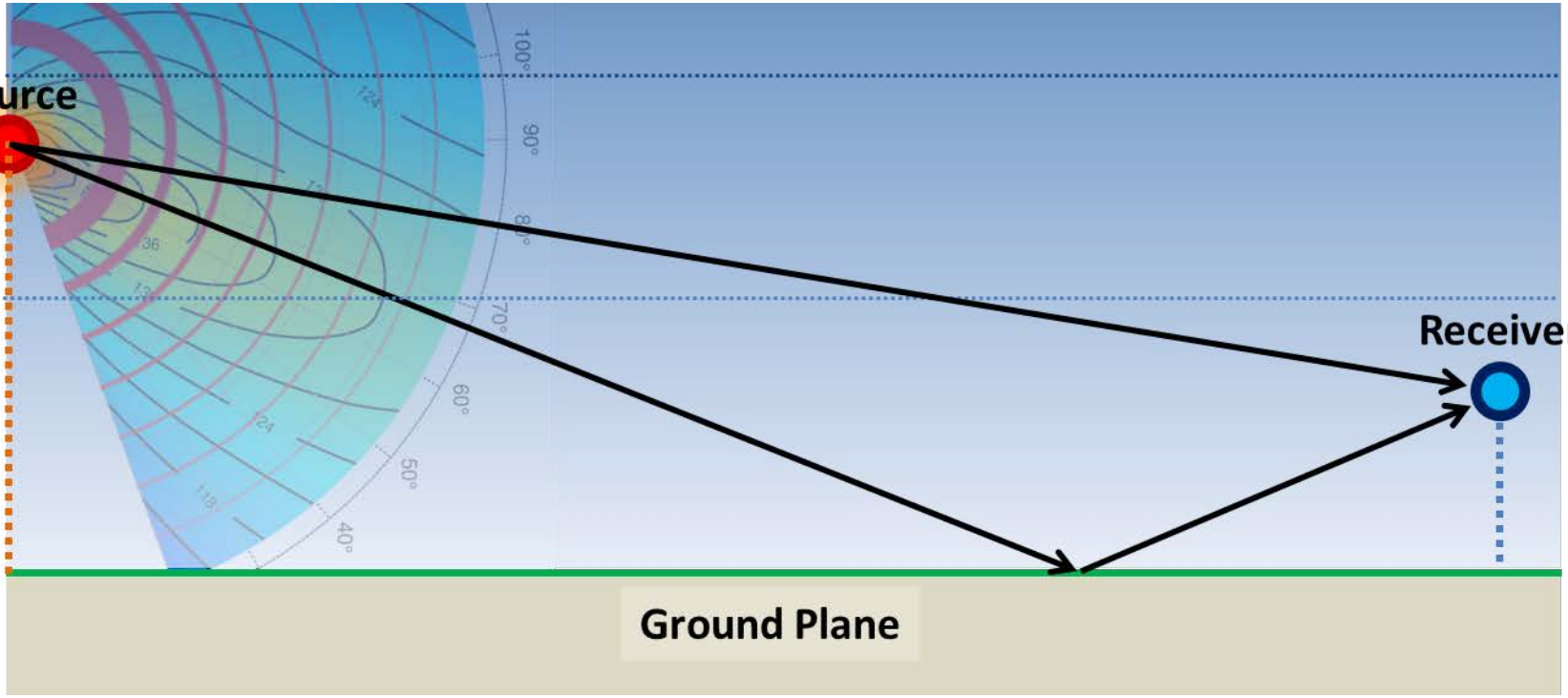


Rocket Launch Noise Modeling

Rocket Noise Source – ***How is the noise source defined?***

Sound Propagation – ***How does it travel?***

Sound Reception – ***How is it received?***

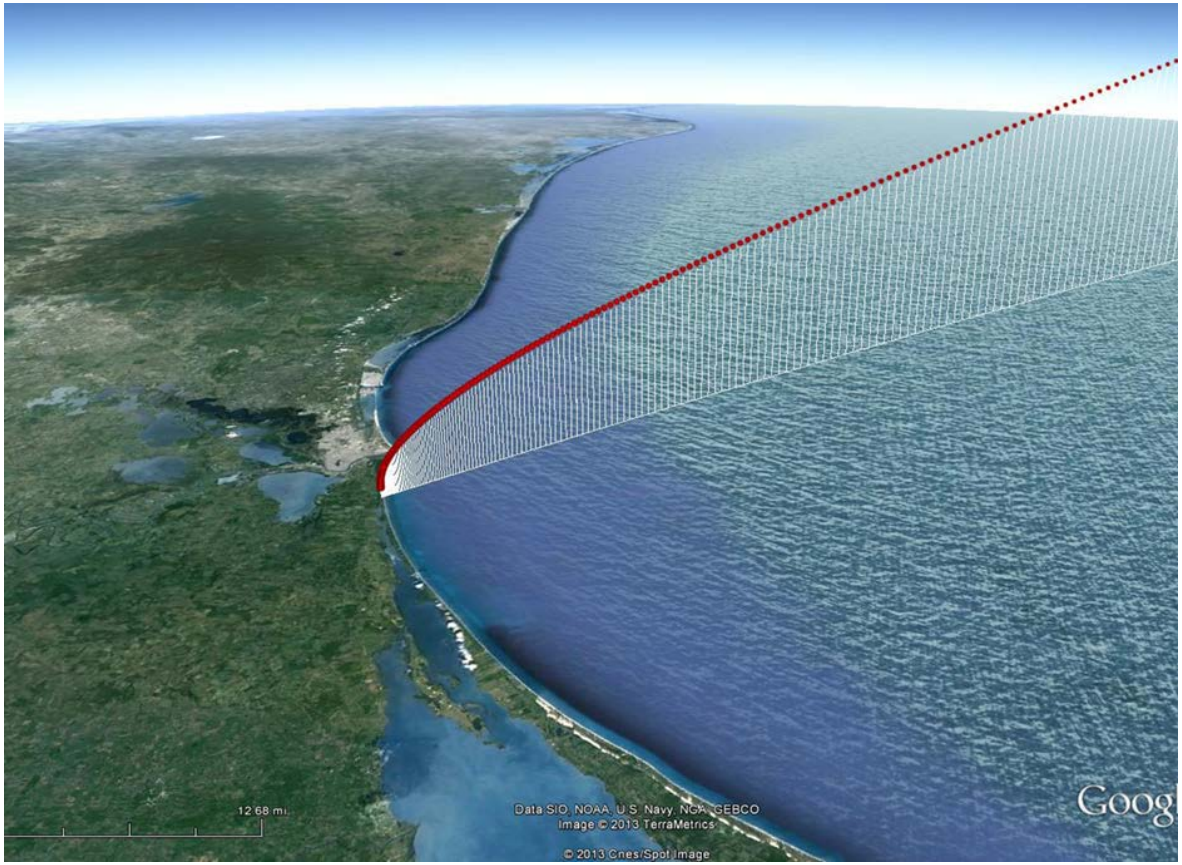


Rocket Launch Noise: Source

Trajectory	Overall Sound Power	Frequency Distribution	Source Directivity

Axisymmetric source assumed at each trajectory point

- Trajectory points must be close enough to accurately represent the moving source
- **Site and Vehicle Specific Trajectory Parameters**:
  - Time
  - Latitude/Longitude
  - Thrust
  - Exhaust Velocity
  - Nozzle Exit Diameter



Rocket Launch Noise: Source

- **Overall Sound Power Prediction**: Based on rocket specific parameters.

$$L_W = 10log\left(\frac{W_{OA}}{10^{-12}}\right),$$

$$W_{OA} = \eta N\left(\frac{TU_e}{2}\right)$$

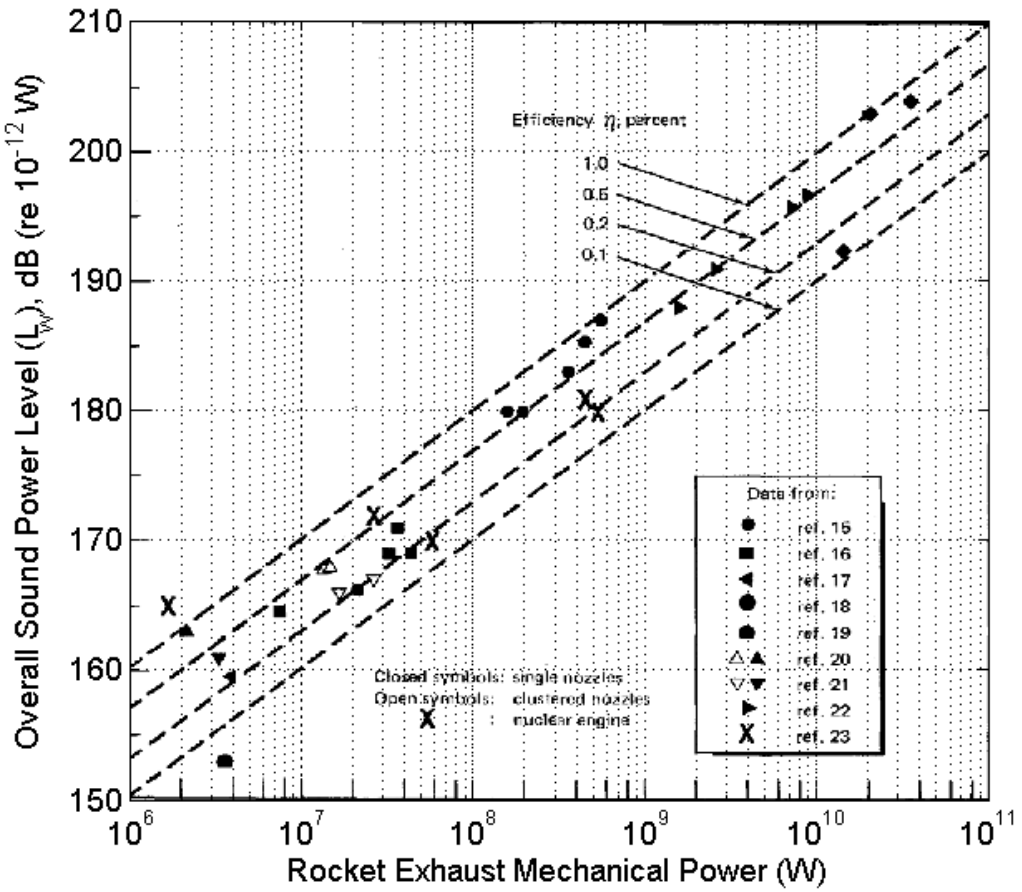
η: acoustic efficiency*

N: # of identical nozzles

T: thrust

U_e: exhaust velocity

NASA SP-8072: Figure 3



* Improvements to acoustic efficiency prediction have been made by Guest and Sutherland

Rocket Launch Noise: Source

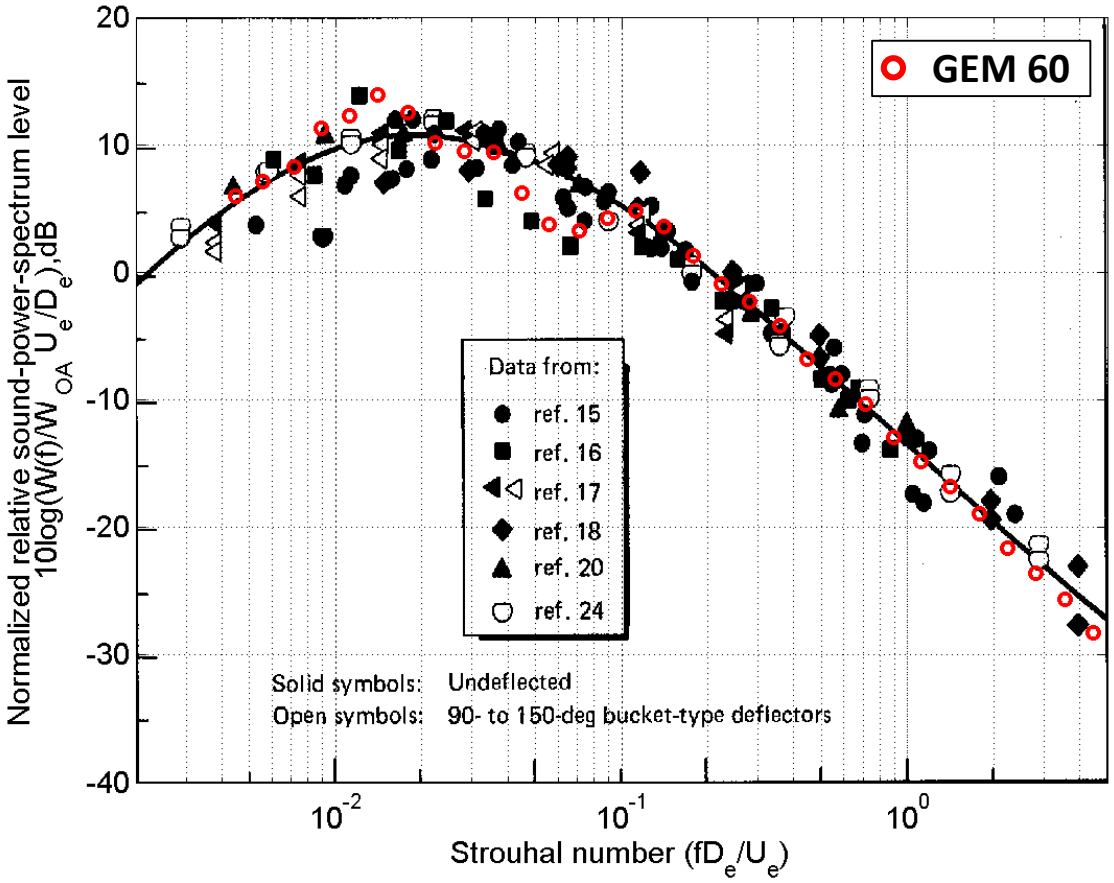
- **Sound Power Spectrum:** Based on normalized relative sound power spectrum level versus Strouhal Number,

$$\frac{W(f)U_e}{W_{OA}d_e} \quad \text{vs} \quad \frac{fd_e}{U_e}$$

d_e: exhaust exit diameter

U_e: exhaust velocity

NASA SP-8072: Figure 5

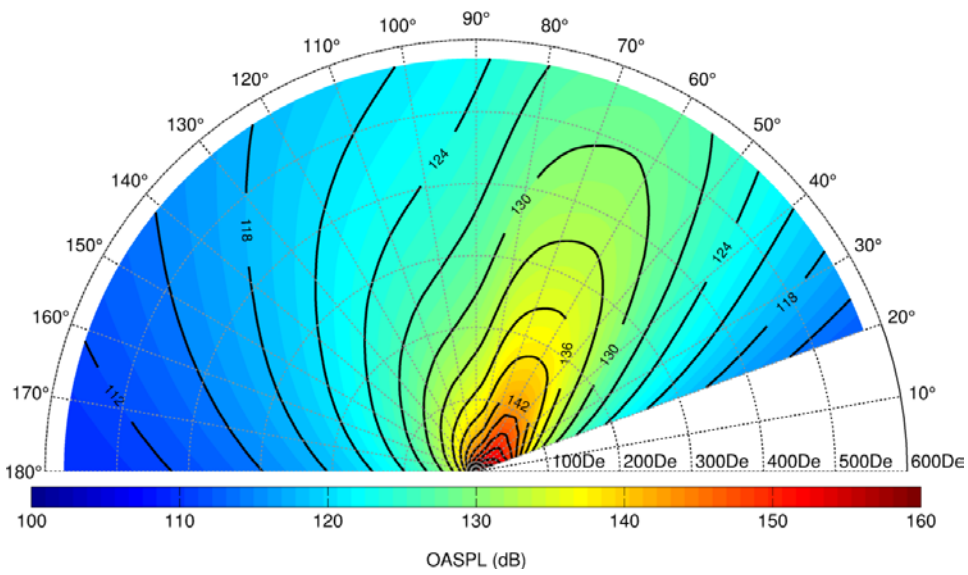


Rocket Launch Noise: Source

Trajectory	Overall Sound Power	Frequency Distribution	Source Directivity

- **Source Directivity:** Focusing of noise source's sound power

- RSRM Measurement: NASA MSFC and Wyle Labs
- Directivity Index: Haynes & Kenny (NASA), AIAA 2009
- Modification of Directivity Curves: James et. al. (BRRC), ASA, 2014



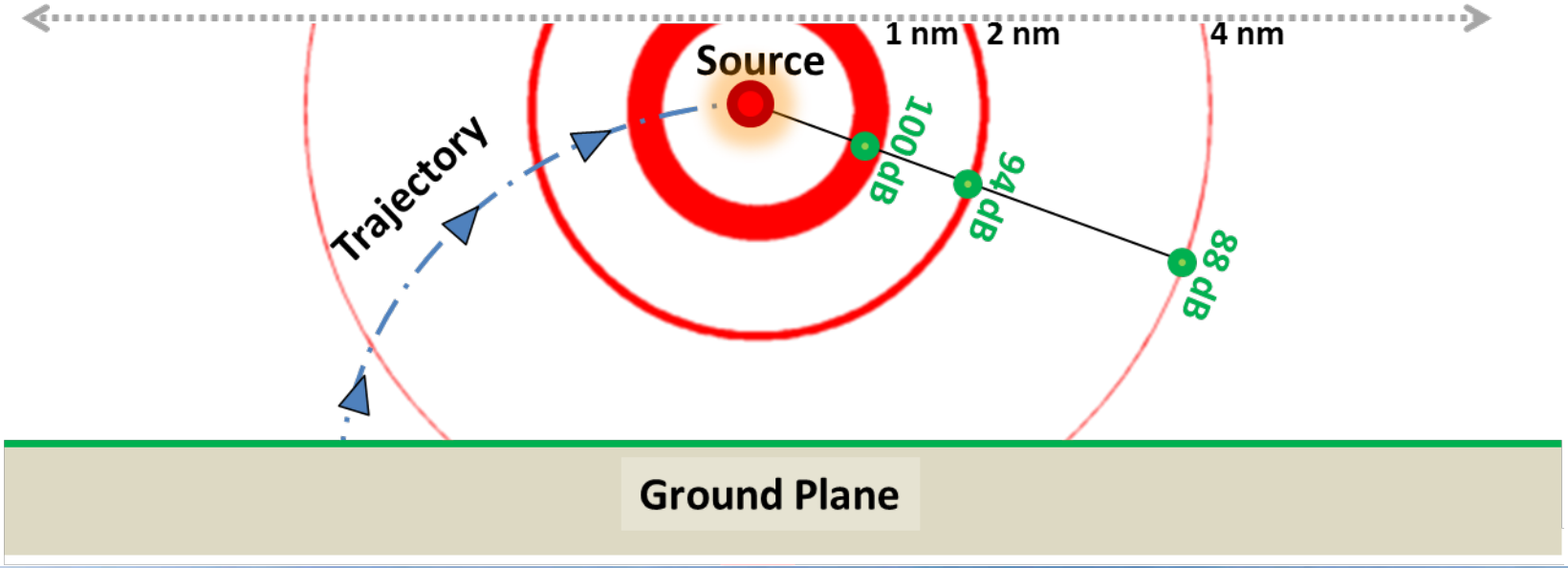
Rocket Launch Noise: Propagation

Spherical Spreading	Ground Interference	Atmospheric Absorption	Nonlinear

- **Spherical Spreading:** Assumes a point source that radiates with a spherical field

$$SPL_{b,p} = L_{w,b} - 10\,log\left(4\pi R^2\right) + DI(b,\theta)$$

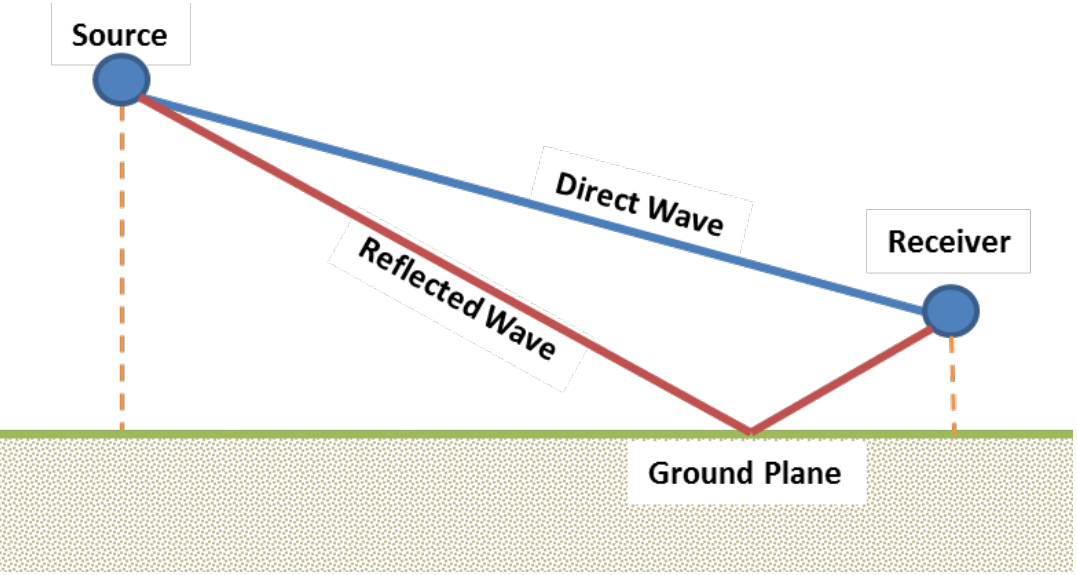
R : distance from source to receiver location

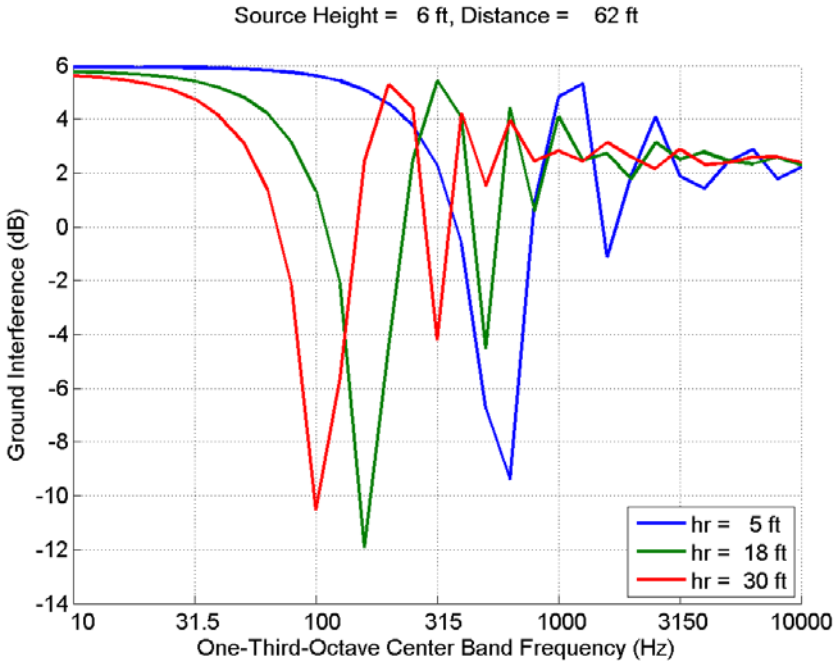


Rocket Launch Noise: Propagation

Spherical Spreading	Ground Interference	Atmospheric Absorption	Nonlinear

- **Ground Interference:** Accounts for the combination of a direct wave (source to receiver) and a reflected wave (source to ground to receiver).*
- **Atmospheric Turbulence:** Minimizes interference effect





*Ground Interference calculated using methods by **Embelton, Diagle, Chessel, Chein and Chorka**

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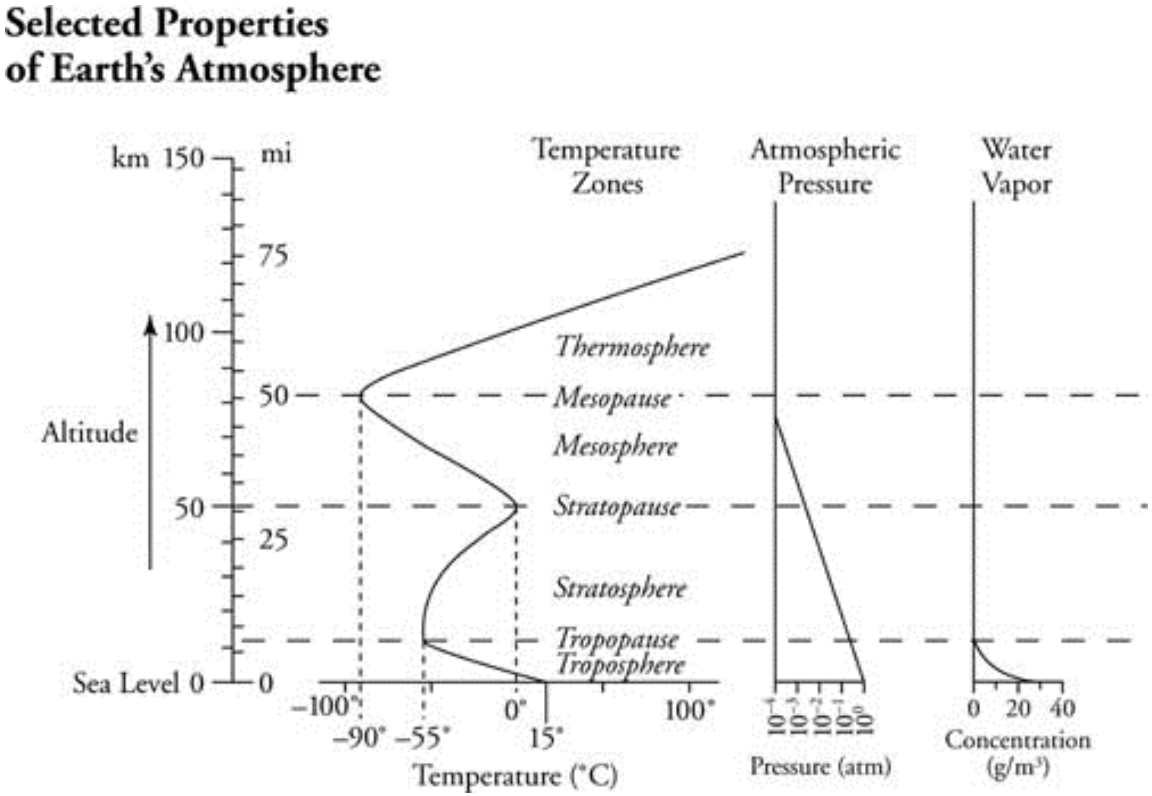
Rocket Launch Noise: Propagation

Spherical Spreading | Ground Interference | Atmospheric Absorption | Nonlinear

- **Atmospheric Absorption:** Measure of the sound attenuation as a function of the temperature, humidity and pressure of the atmosphere.
- Calculation method described by ANSI S1.26-1995
- Sum of attenuation through each layer

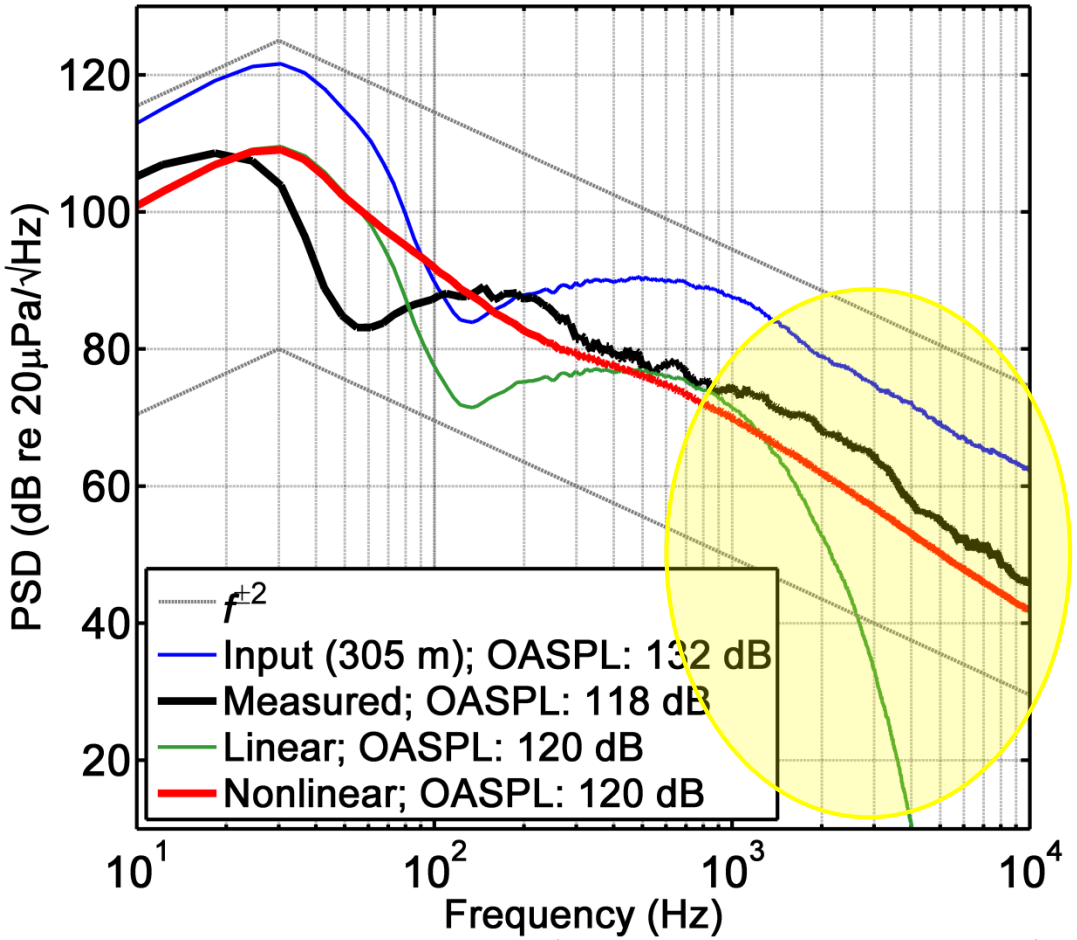


Note: Model utilizes a site specific or U.S. Standard Day 1976 atmospheric profile

Rocket Launch Noise: Propagation

Spherical Spreading | Ground Interference | Atmospheric Absorption | Nonlinear

- **High Amplitude Noise Source with high shock content**
- **Nonlinear effects** counteract the effect of atmospheric absorption
- **Supporting research** by McInerny, Journal of Aircraft, 1996 & Morfey and Howell, AIAA 1981
- **Recent military jet noise measurements** have demonstrated nonlinear propagation effects



*Michael Muhlestein et. al., ASA POMA (2013).

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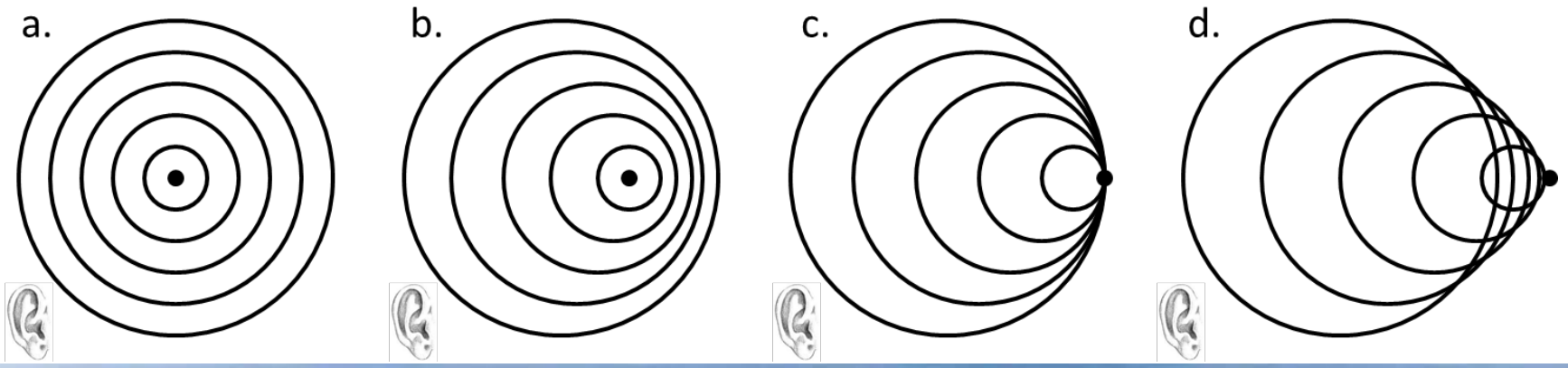
Rocket Launch Noise: Receiver

- **Doppler Effect:** changes the frequency of a wave for an observer moving relative to its source. Received frequency is higher during approach and lower during recession.

Stationary source	***slower than speed of sound***	***traveling at speed of sound***	***faster than speed of sound***
$v = 0$	$v < c$	$v = c$	$v > c$



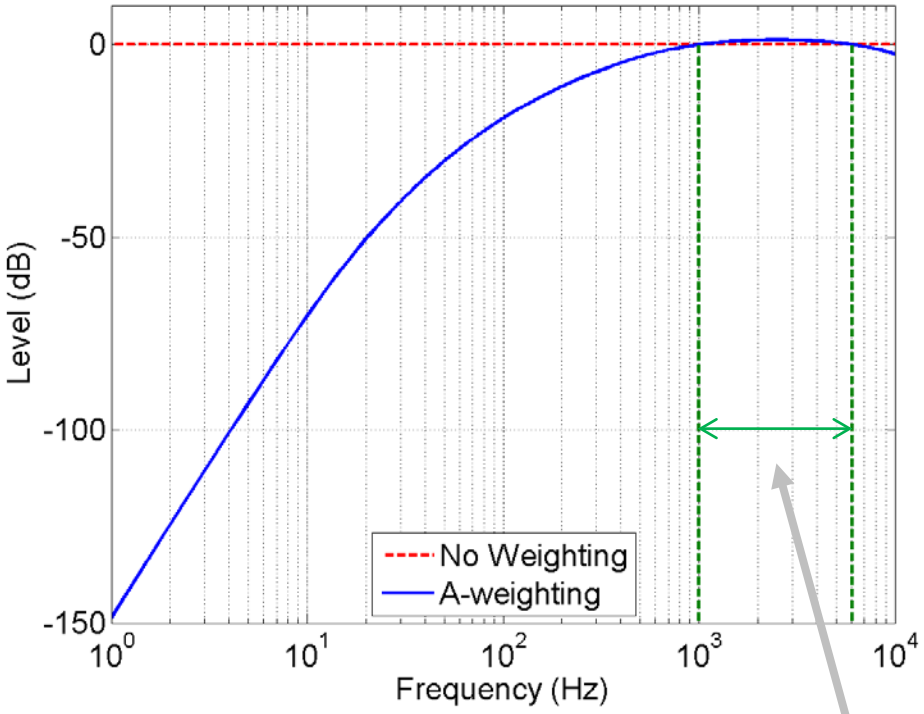
Rocket Launch Noise: Receiver

- **Loudness:** Measured in decibels (dB)

$$L = 20\log(P/P_0)$$

$P_0 = 20\mu\text{Pa}$, quietest audible sound

- Human ear is not equally sensitive to all frequencies
- **Filters** shape levels in reference to how they are perceived
- **"A-weighting" filter** approximates the relative loudness perceived by the human ear



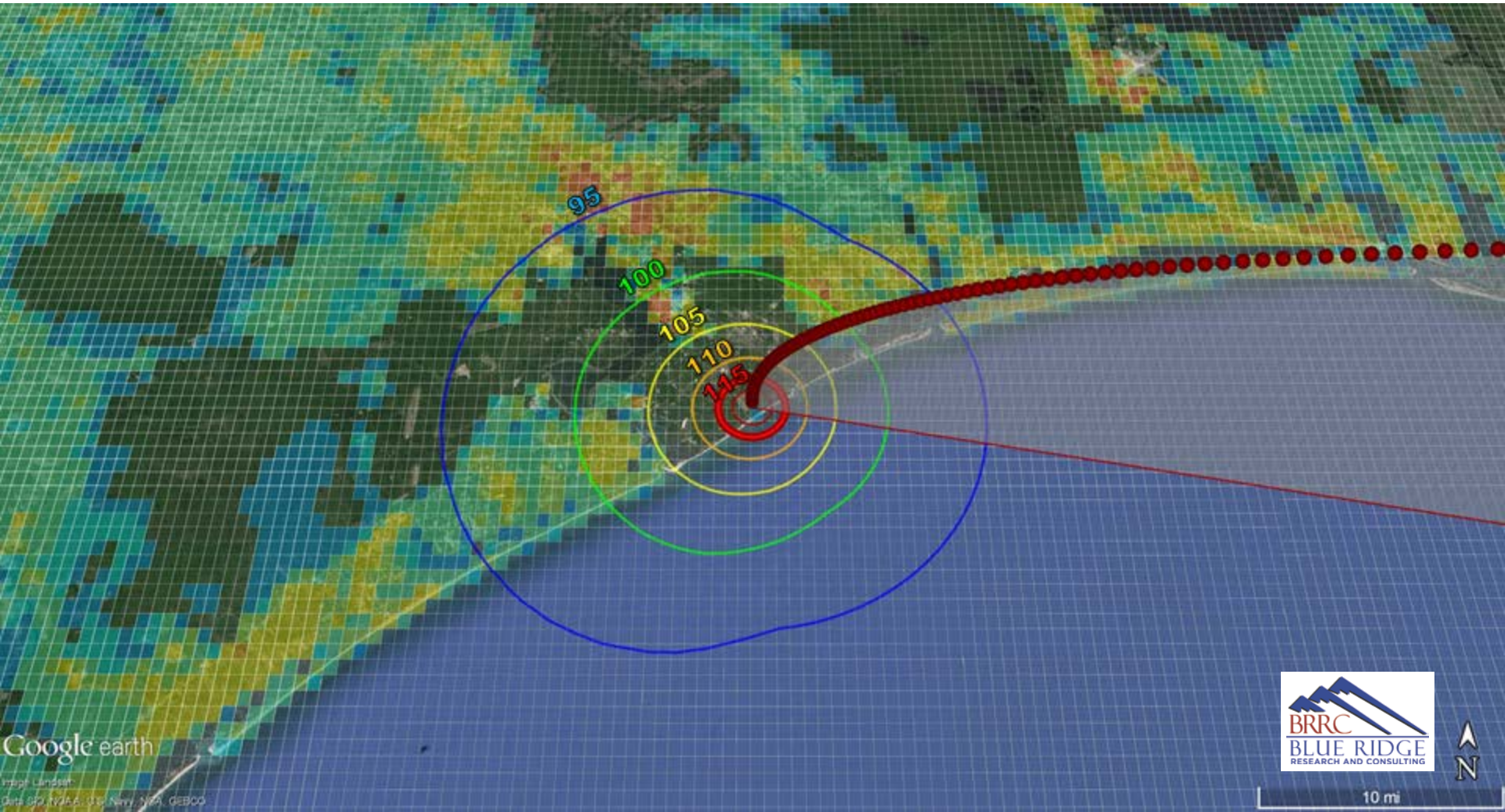
Human hearing most sensitive to frequency region between 1kHz and 6kHz

Rocket Launch Noise: Receiver

- ***Hearing Conservation*:** Identify population exposed to high levels based on A-weighted Maximum (L_{Amax})
  - Overlay 115 dBA contour over local maps and/or census blocks
  - Conservative approach (flags areas of concern)
- ***Structural Damage*:** Identify probability of damage claim based on data from NASA Stennis
  - 111 dB maximum (unweighted) level, 1 out of 1,000 houses claims
  - 120 dB maximum (unweighted) level, 1 out of 100 houses claims
  - Conservative approach (flags areas of concern)
- **Day-Night Average Sound Level (DNL):** Identify community annoyance, required by FAA (Order 1050.1E, Change 1)
  - Most widely accepted metric in the US for transportation noise
  - May not be most applicable for rocket launches (limited studies/infrequent occurrence)

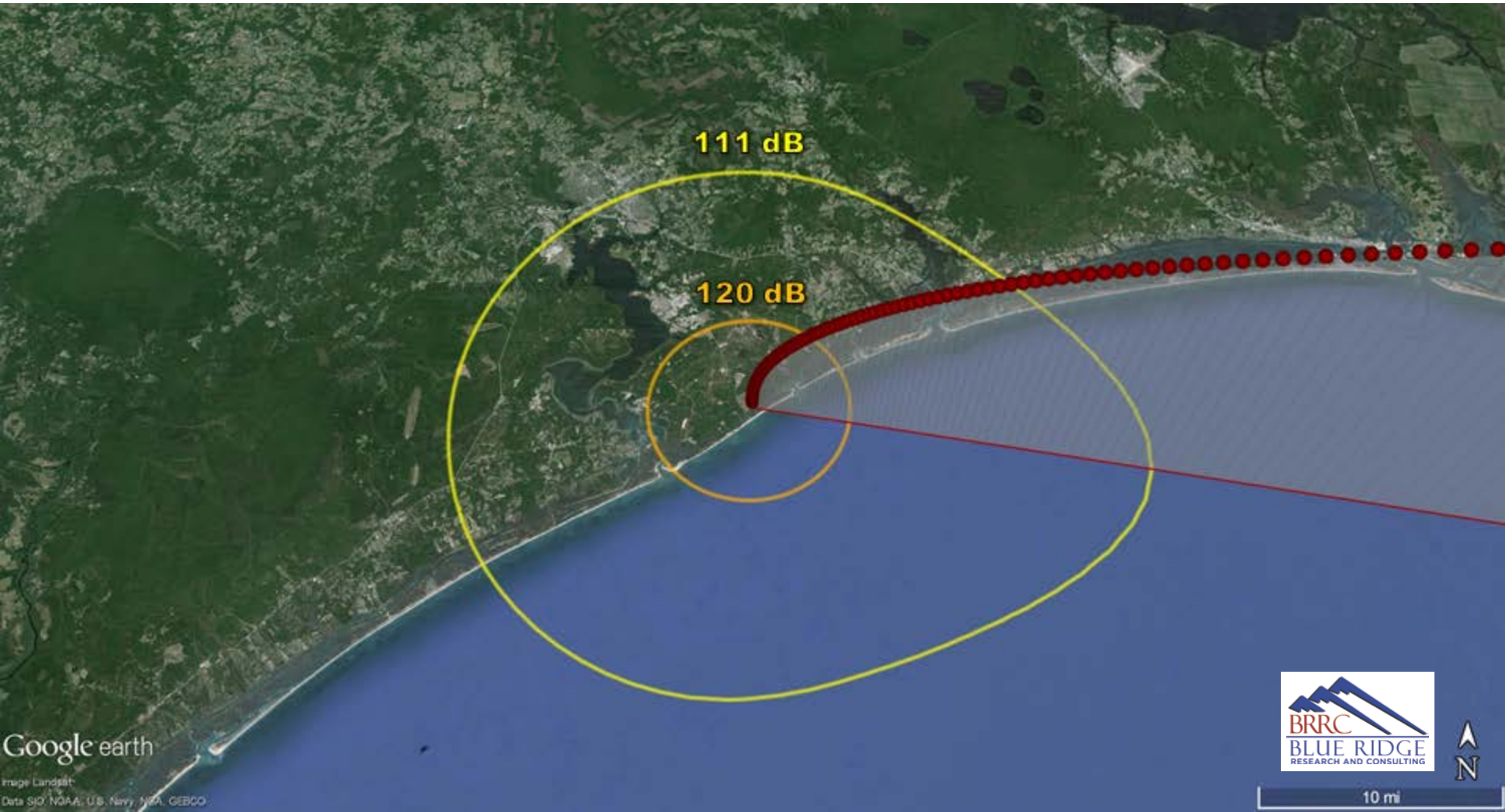
Rocket Launch Noise: Hearing Conservation

- *Screen for potential population impacts, L_{Amax} =115 dBA*



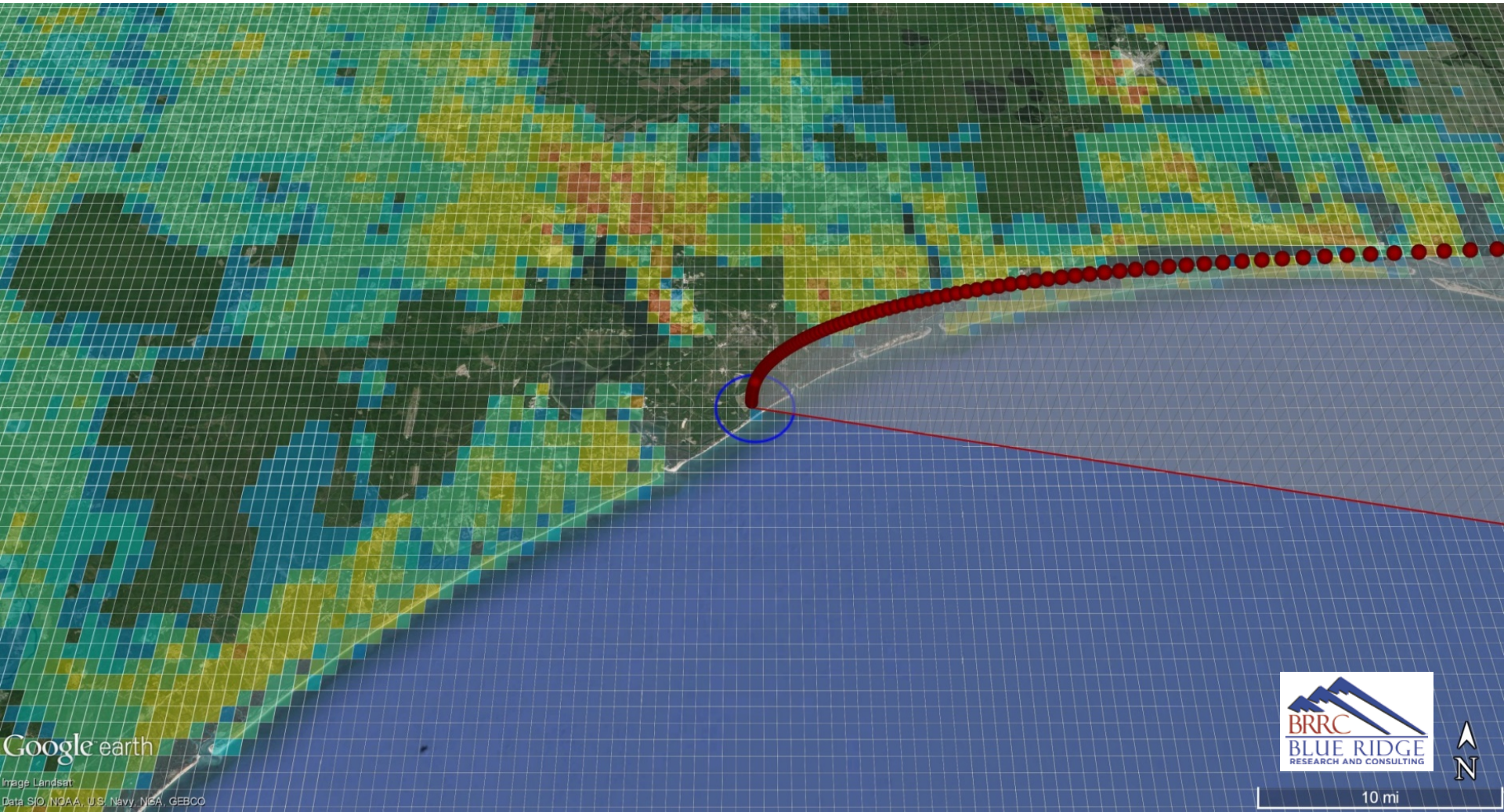
Rocket Launch Noise: Structural Damage

- *Screen for potential structural damage claims, L_{max}*

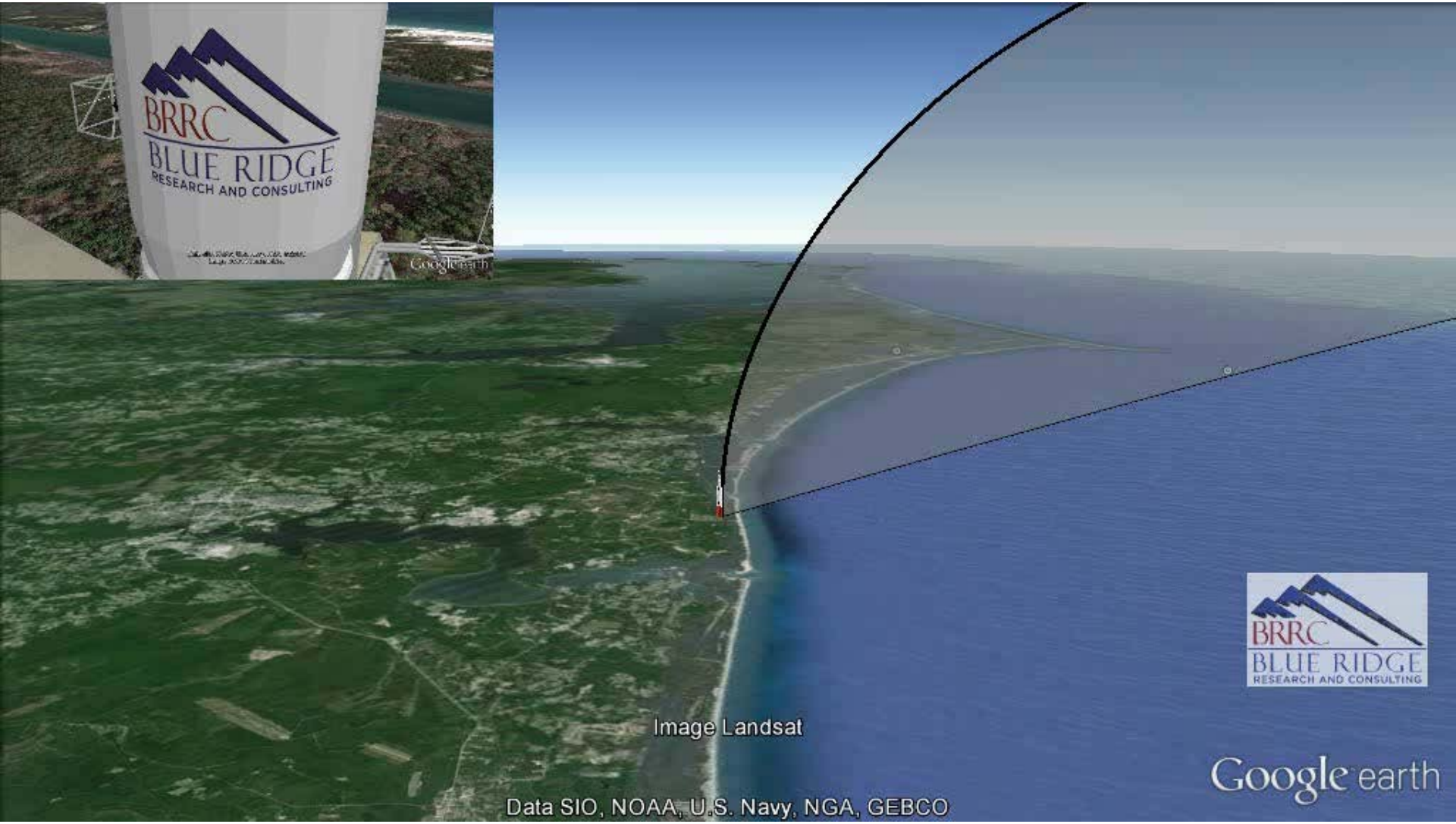


Rocket Launch Noise: DNL

- *Determine population affected by > 65 dBA DNL*



Rocket Launch Noise: Simulation



Conclusions

- Emerging need for rocket environmental noise modeling and impact criteria
- Aircraft noise and rocket noise may require different impact criteria
- Further measurements and research are needed to improve:
  - Rocket source characterization
  - Long-range sound propagation
  - High amplitude waveforms through complex atmosphere
  - Environmental and community impacts


Source: SpaceX

Questions? (or is it time for lunch)