Annoyance Model Assessments of Urban Air Mobility Vehicle Operations

Stephen A. Rizzi, Andrew W. Christian, and Stefan J. Letica
NASA Langley Research Center

Shane V. Lympany
Blue Ridge Research and Consulting, LLC.

30th AIAA/CEAS Aeroacoustics Conference
CNMSB-01, Community Noise Metrics: Psychoacoustics
AIAA-2024-3018
4 June 2024

Outline

- Motivation and Goal
- Annoyance Model in the Presence of Masking
- Aircraft Signal Generation
- Masking Noise
    - Recordings
    - Modeled
- Results
    - Overflight
    - Point-To-Point
- Summary and Future Work

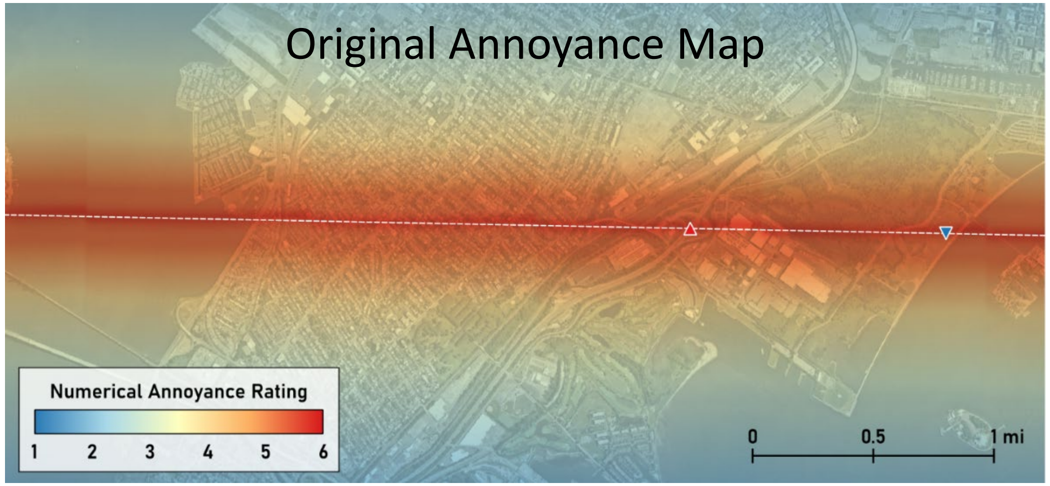
Motivation and Goal

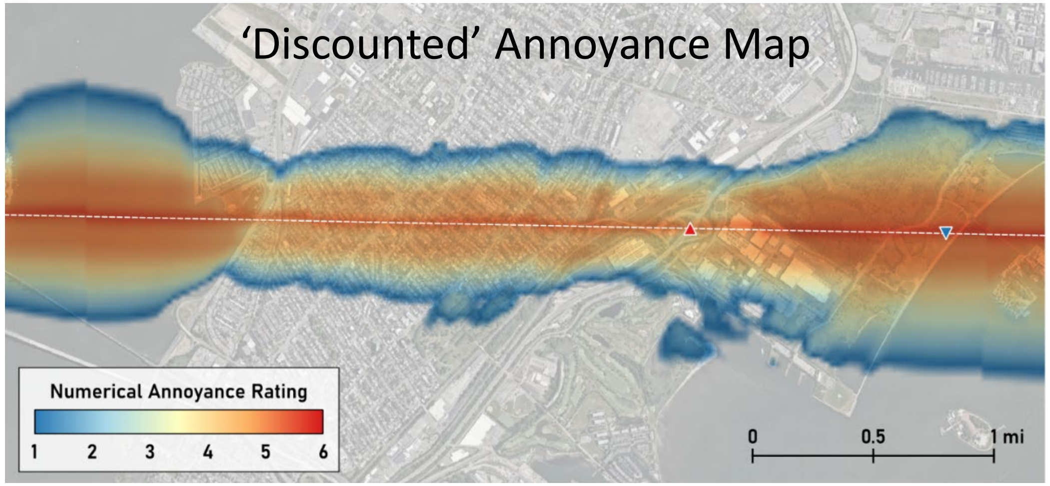
- Motivation - Current aircraft noise regulations do not directly take into account environmental noise (“background” or “ambient”) that may be present in their operational environments.
  - Past psychoacoustic testing has shown that sounds are less annoying when they are masked.

Signal Alone

Signal + Masker

- Goal - assess annoyance to UAM vehicle operations over a representative community using a recently developed annoyance model in which the effect of masking is taken into account.


Original Annoyance Map


‘Discounted’ Annoyance Map

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Annoyance Model in the Presence of Masking

- Desired behaviors
  - Effect of ambient noise on annoyance not strong if signal >> ambient.
  - Reduction in annoyance to the signal if signal at least partially masked by ambient.

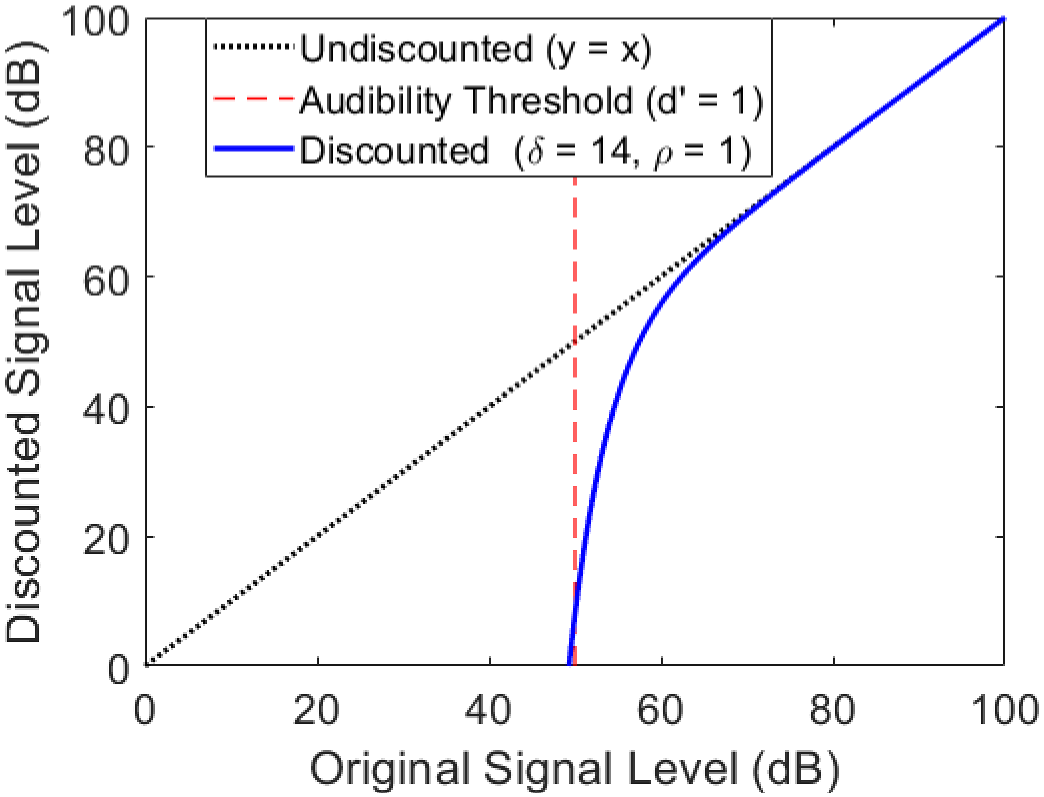
- Discounting model

$$L_{i,t}\Big|_{Disc} = L_{i,t} - \frac{\alpha}{\left(\frac{d'_{i,t}}{\delta}\right)^{\rho}}$$

$L_{i,t}$: signal spectrogram

$d'_{i,t}$: detectability index spectrogram

α, δ, ρ : parameters from human response testing*



* Boucher, M.A., et al., "A psychoacoustic test on the effect of masking on annoyance to urban air mobility vehicle noise," 186th Meeting of the ASA, Ottawa, Canada, 2024.

Tracy, T.D., et al., "An annoyance model for urban air mobility vehicle noise in the presence of a masker," Noise-Con 2024, New Orleans, LA, 2024.

The d-Prime Part

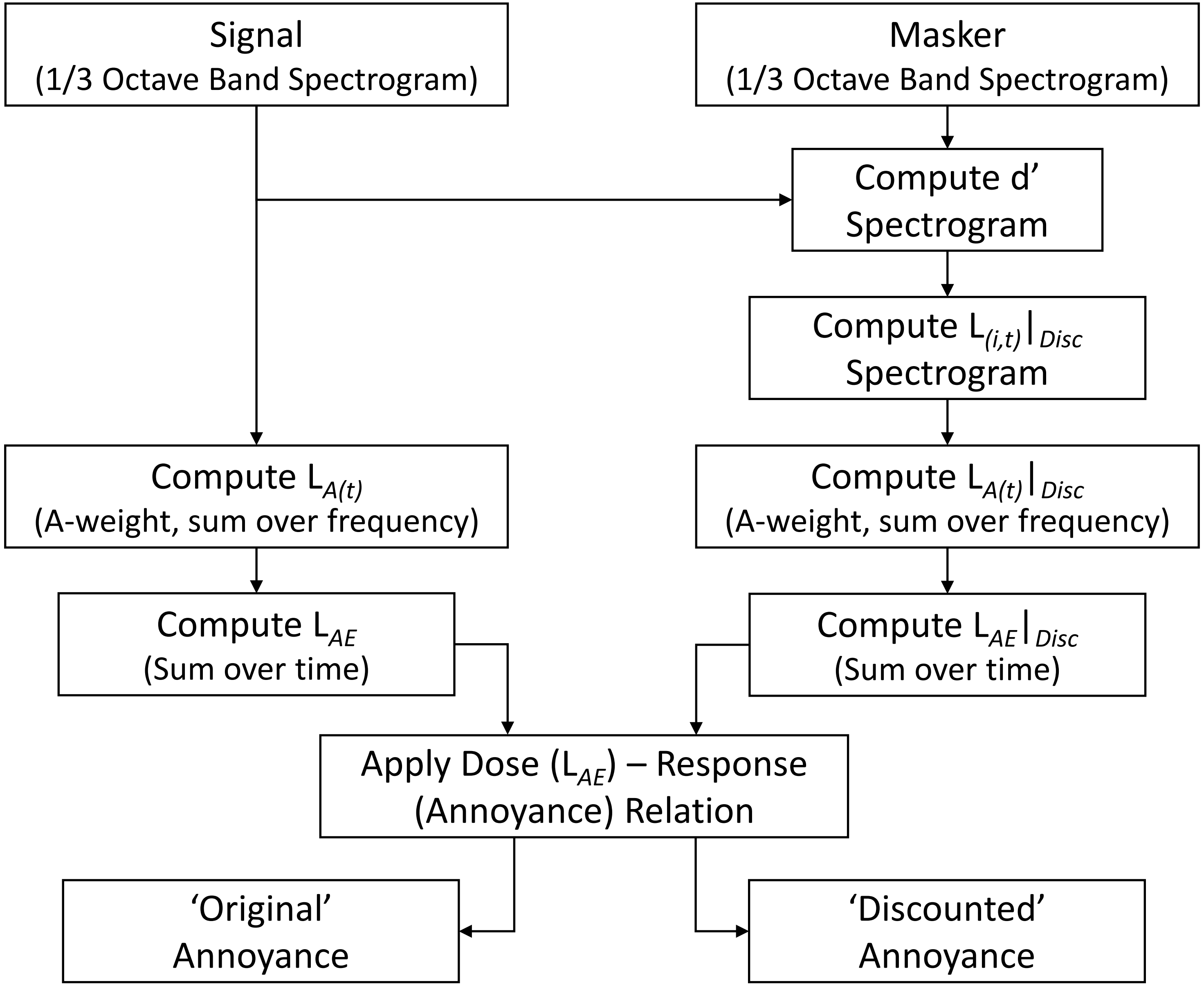
- Some things about d'
  - $d' \approx 1$ - Signal level close to masker level such that signal audible about 50% of the time.
  - Doubling of d' corresponds to about 3 dB gain in signal level.
- In this work, d' computed using simple “power spectrum model of masking.”
  - 1/3 octave band sound pressure levels at 0.5 s intervals.
  - Computationally reasonable audibility prediction program.

$$d'_{i,t} = \mathbb{D}_i \cdot \frac{s_{i,t}}{n_{i,t} + e_i}$$

$$\mathbb{D}_i = \underbrace{\eta}_{\text{Efficiency Factor}} \cdot \underbrace{\sqrt{\Delta t} \cdot \sqrt{w_{\text{OTOB},i}}}_{\text{Bandwidth-Time (BT) Correction}} \cdot \underbrace{\sqrt{\frac{w_{\text{OTOB},i}}{w_{AF,i}}}}_{\text{Auditory Filter Bandwidth Correction}} \cdot \underbrace{\kappa_i}_{\text{High-Freq. Adj.}}$$

$$e_i = \mathbb{D}_i \cdot \frac{\underbrace{s_{MAF,i}}_{\text{Minimum Audible Field}}}{2}$$

Annoyance Model – How it Works



Signal
(1/3 Octave Band Spectrogram)

Masker
(1/3 Octave Band Spectrogram)

Compute d’
Spectrogram

Compute $L_{(i,t)}|_{Disc}$
Spectrogram

Compute $L_{A(t)}$
(A-weight, sum over frequency)

Compute $L_{A(t)}|_{Disc}$
(A-weight, sum over frequency)

Compute L_{AE}
(Sum over time)

Compute $L_{AE}|_{Disc}$
(Sum over time)

Apply Dose (L_{AE}) – Response
(Annoyance) Relation

‘Original’
Annoyance

‘Discounted’
Annoyance

$$d'_{i,t} = \mathbb{D}_i \cdot \frac{s_{i,t}}{n_{i,t} + e_i}$$

$$L_{i,t}\big|_{Disc} = L_{i,t} - \frac{\alpha}{\left(\dfrac{d'_{i,t}}{\delta}\right)^{\rho}}$$

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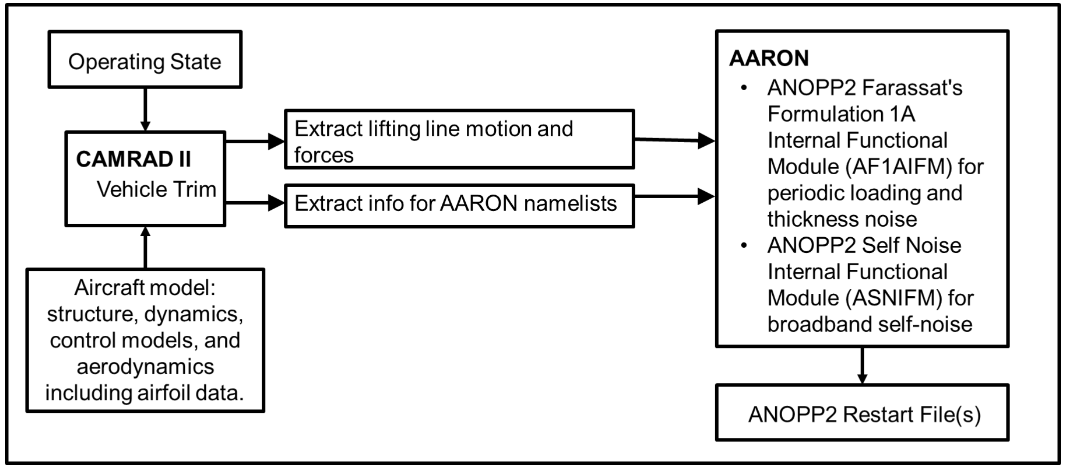
Aircraft Signal Generation

NASA Reference Vehicle

- All-electric variant
- 3-bladed rotors
- 6469 lb. (2934 kg) GTOW
- V_{max} 109 KTAS (202 km/h)

Source Noise Prediction



Operating State

CAMRAD II
Vehicle Trim

Aircraft model: structure, dynamics, control models, and aerodynamics including airfoil data.

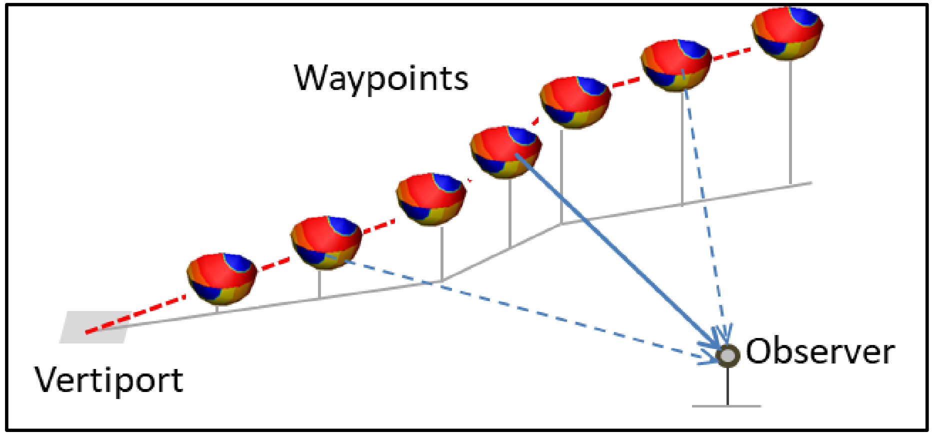
Extract lifting line motion and forces

Extract info for AARON namelists

AARON
- ANOPP2 Farassat's Formulation 1A Internal Functional Module (AF1AIFM) for periodic loading and thickness noise
- ANOPP2 Self Noise Internal Functional Module (ASNIFM) for broadband self-noise

ANOPP2 Restart File(s)

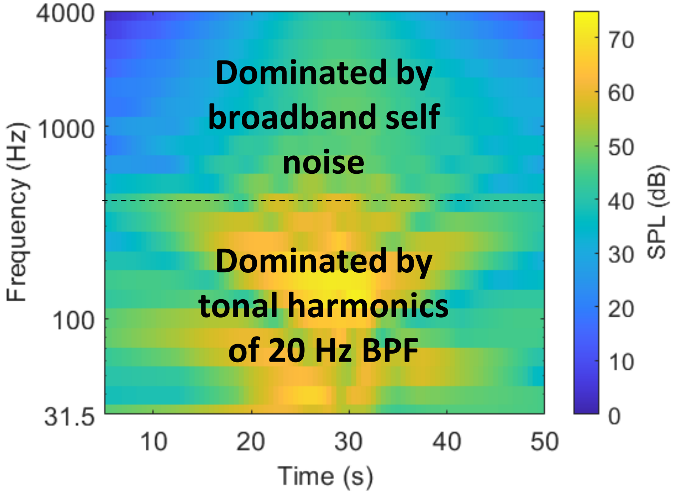
Simulation Using ANOPP2 Mission Analysis Tool (AMAT)



Repeat over grid of observers

Synchronize using ANOPP2 Explicit Observer Time

Signal Spectrogram for Overflight at 167 km/h and 305 m Altitude



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Recorded Masking Noise

[Source: NASA]

Two Recording Sites in NYC

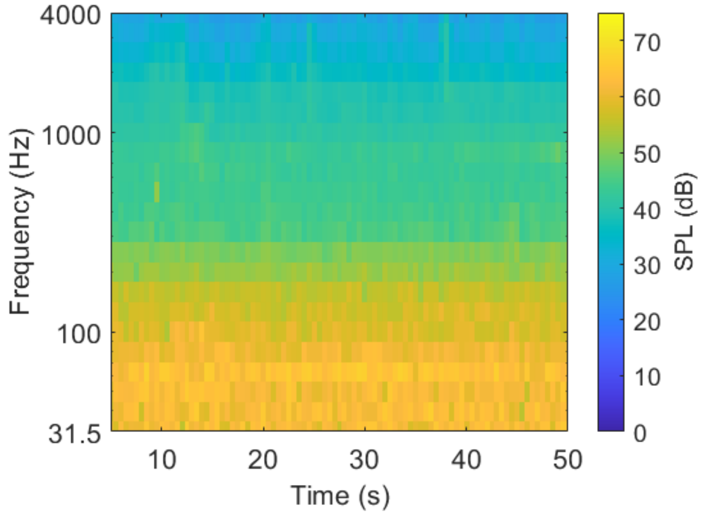
Central Park **City Hall Park**

Masker Only

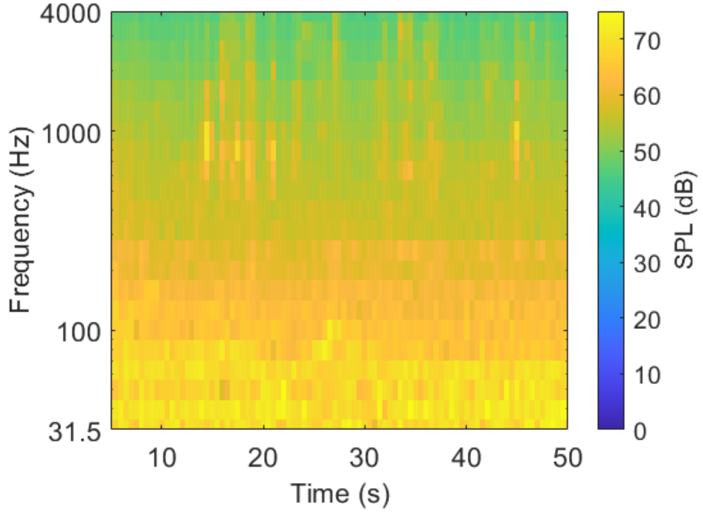
Signal + Masker

Sounds available for download at https://stabserv.larc.nasa.gov/flyover/

Masker Spectrograms



Central Park



City Hall

Modeled Masking Noise

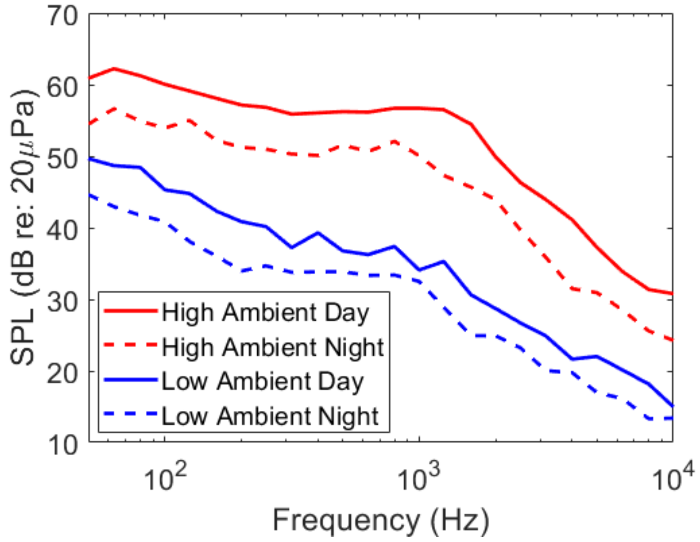
BRRC AMBIENT Model

- A physics-informed machine learning (ML) model of ambient soundscapes.
  - Model composed of anthropogenic, biological, and geophysical sounds.
  - Generates spatially, temporally, spectrally varying maps.

Ambient level = *f* (geospatial features, physics-based noise)

- *f* determined by fitting ensemble of ML regression models at locations where geospatial features, predicted traffic noise, and ambient levels are known.
- Geospatial features at 30 m resolution include population density, land cover, topography, climate.
- Physics-based noise includes road traffic noise, but not (currently) aviation noise.

Day/Night Masker Spectra



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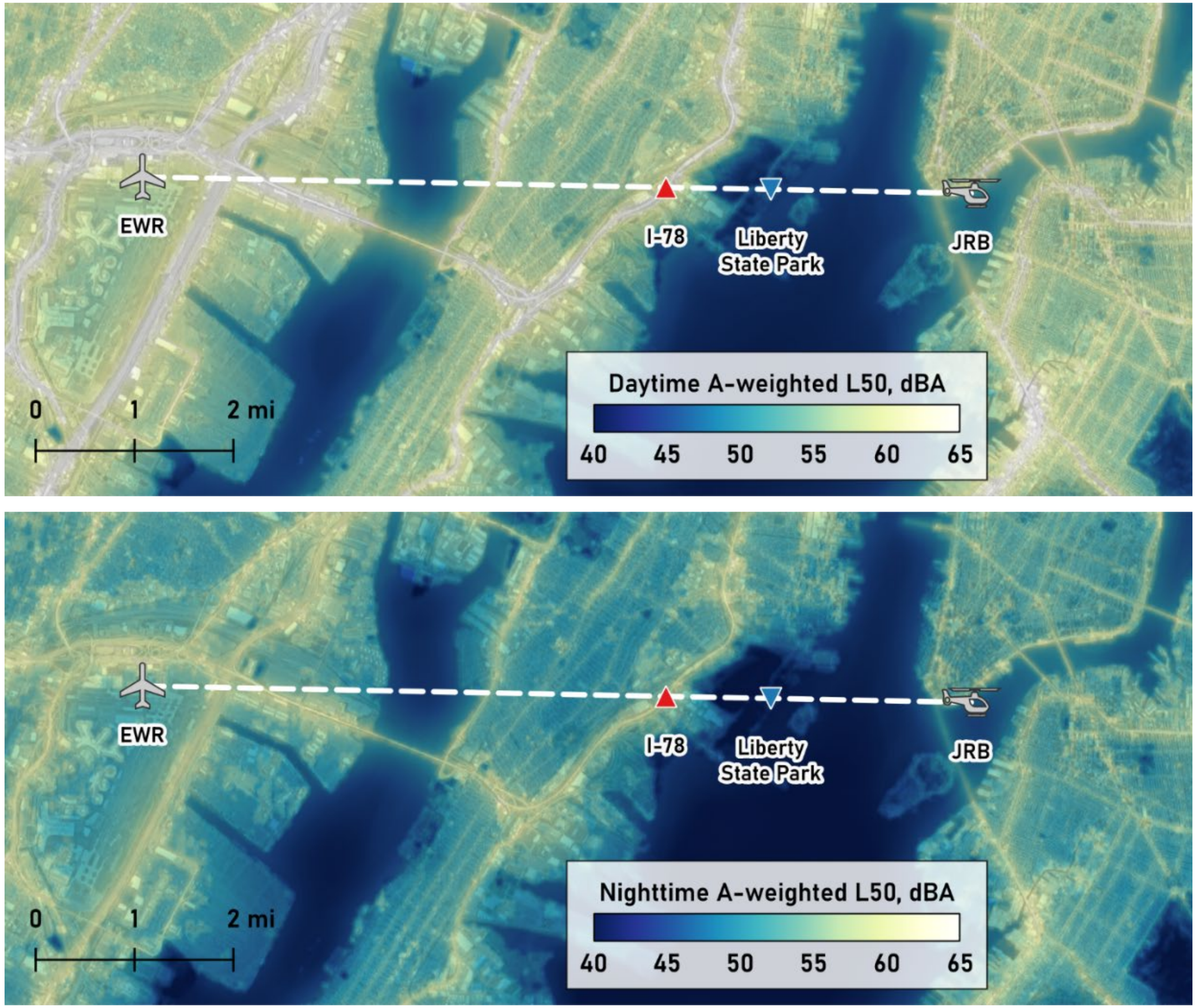
Day/Night Median Noise Levels



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Overflight Case – d' Spectrograms

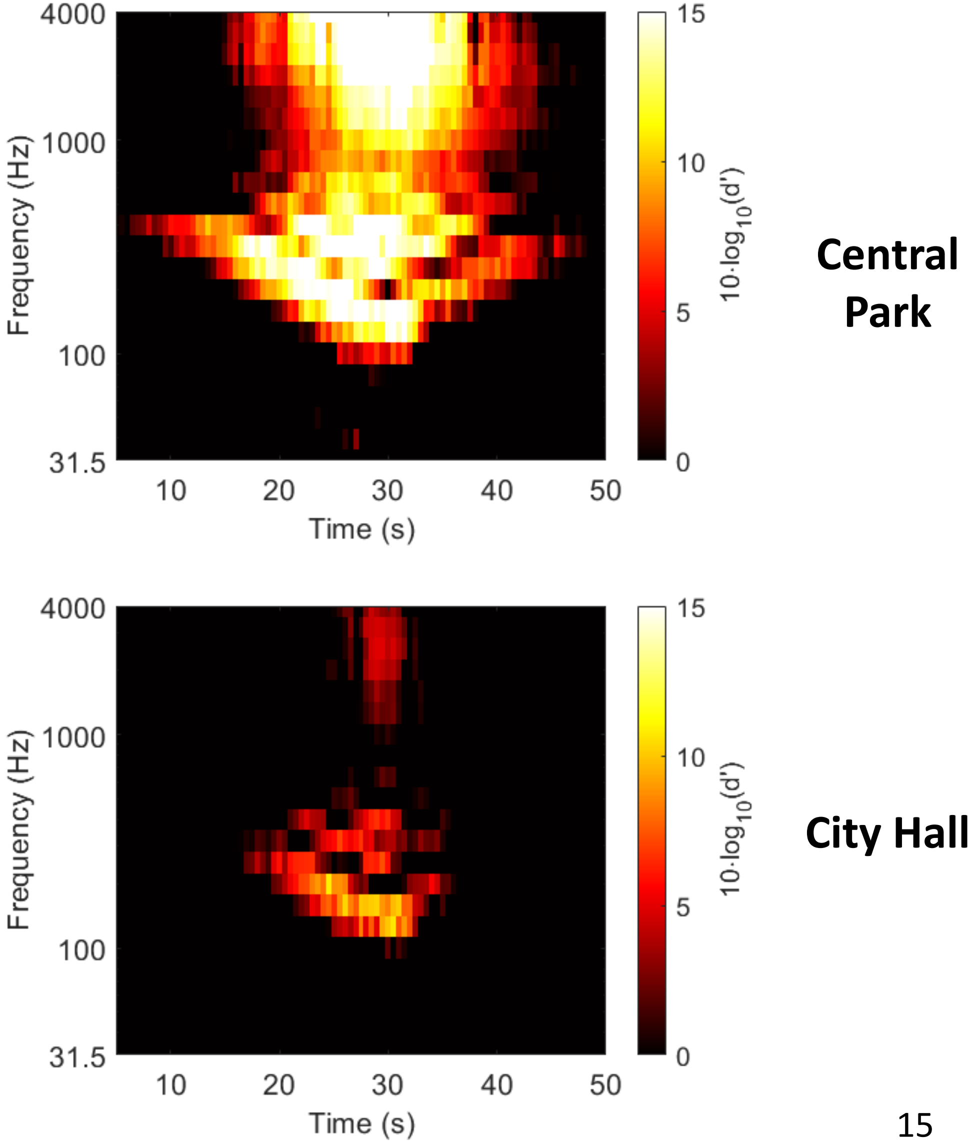
Scenario

- Signal: Overflight at 167 km/h and 305 m altitude.
- Maskers: Central Park (CP) and City Hall (CH) recordings.
- Observer on ground track.

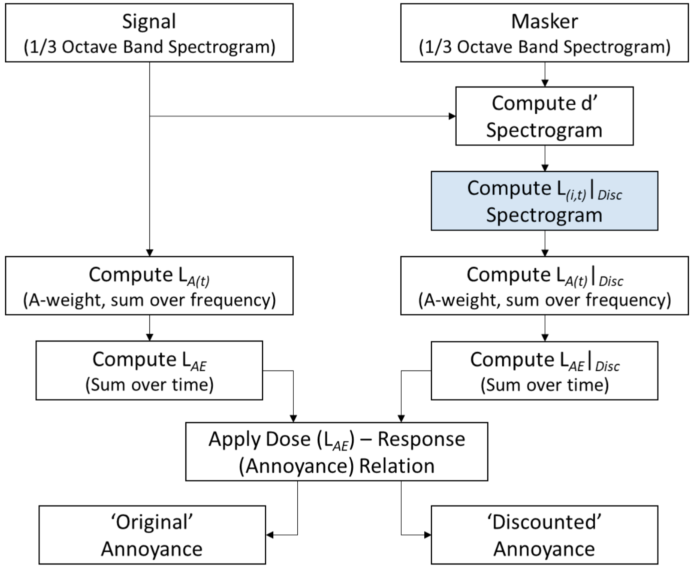
Some Observations

- $d' < 1$ (functionally inaudible).
- Greater duration and frequency of detection for CP masker relative to CH masker is expected.
    - Magnitude of CP masker < CH masker over entire frequency range.
    - Magnitude difference increases with increasing frequency.
- Spectrograms can be used to identify time and frequency with highest probably of detection.
    - ~ 27 s @ 125-160 Hz CH, ~ 4 kHz CP.

d' Spectrograms



Overflight Case – Discounted Signal, L_A, and L_{AE}



Signal (1/3 Octave Band Spectrogram)

Masker (1/3 Octave Band Spectrogram)

Compute d' Spectrogram

Compute $L_{(i,t)}|_{Disc}$ Spectrogram

Compute $L_{A(t)}$ (A-weight, sum over frequency)

Compute $L_{A(t)}|_{Disc}$ (A-weight, sum over frequency)

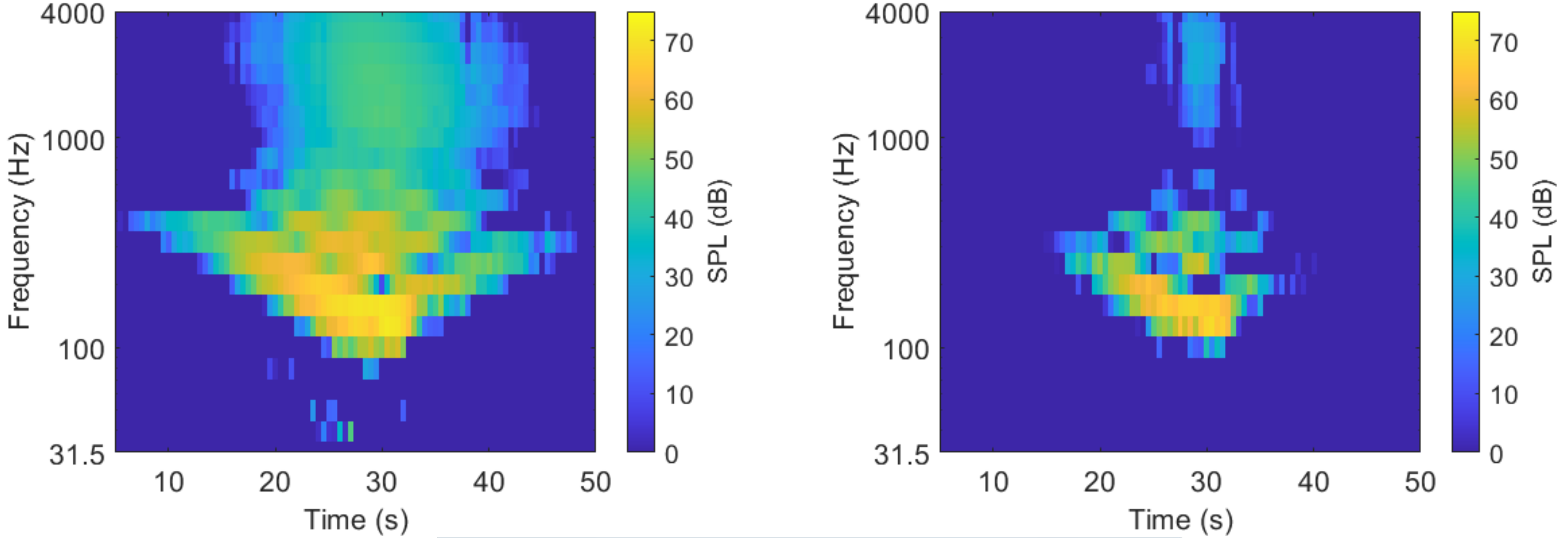
Compute L_{AE} (Sum over time)

Compute $L_{AE}|_{Disc}$ (Sum over time)

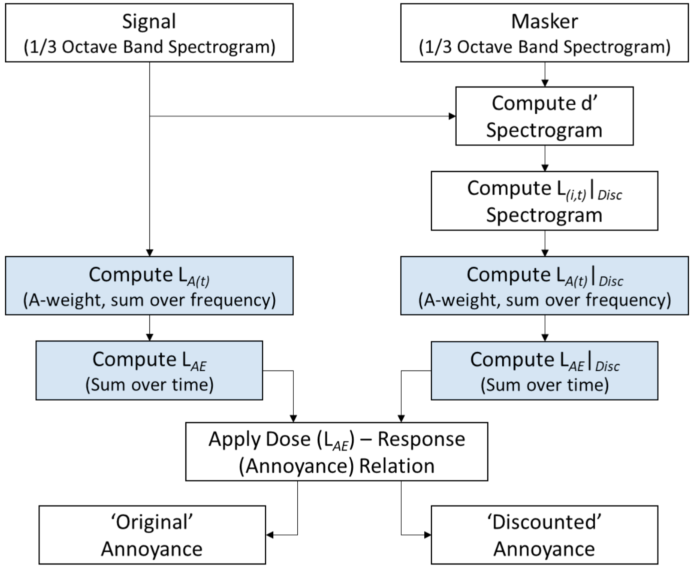
Apply Dose (L_{AE}) – Response (Annoyance) Relation

'Original' Annoyance

'Discounted' Annoyance



Larger discount in L_{AE} for CH masker



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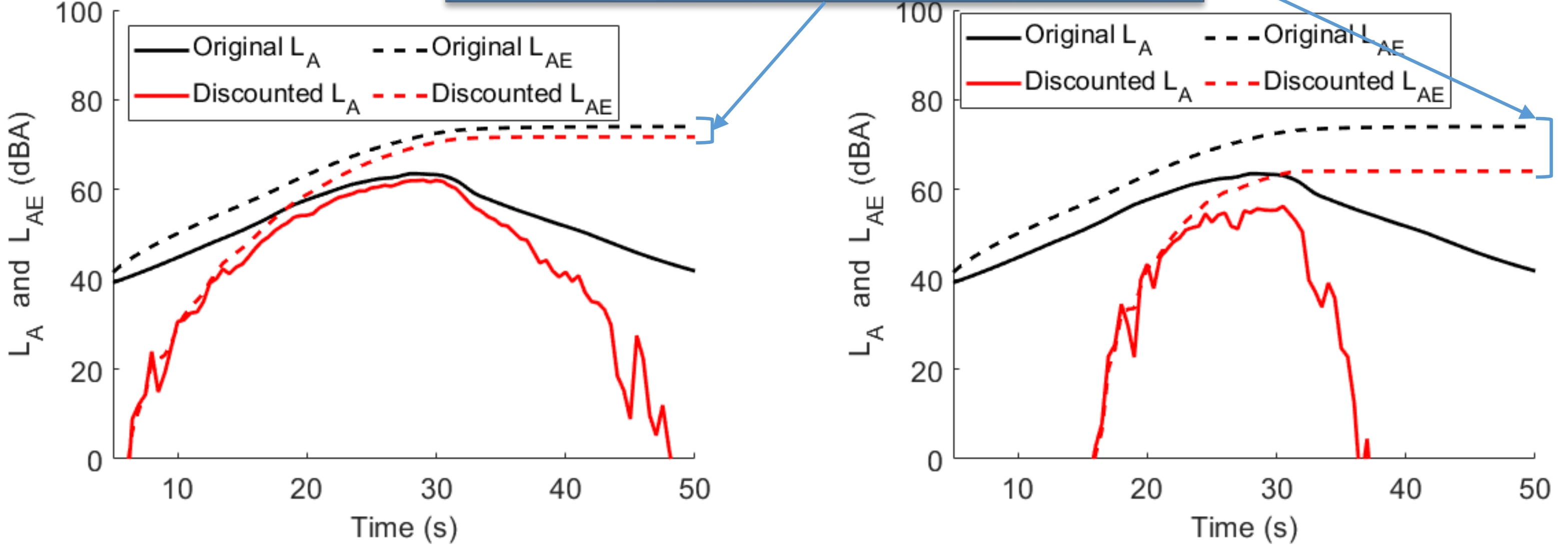
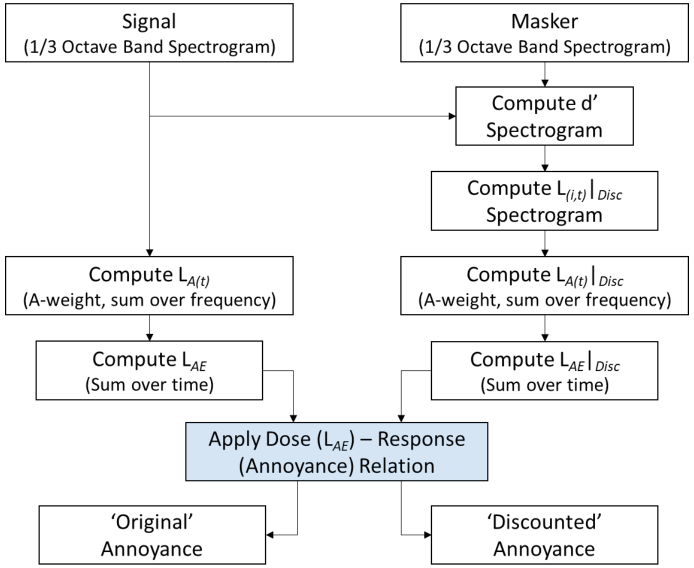
'Discounted' Annoyance



Central Park **City Hall**

Overflight Case – Dose-Response and Annoyance



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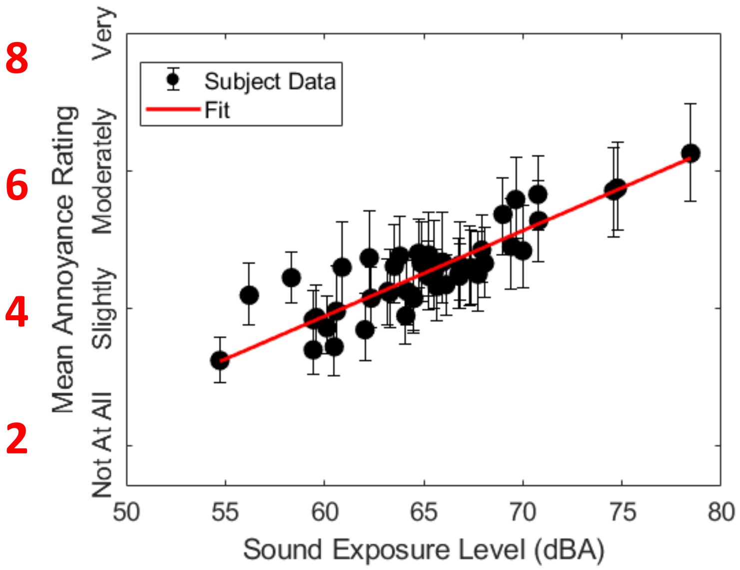
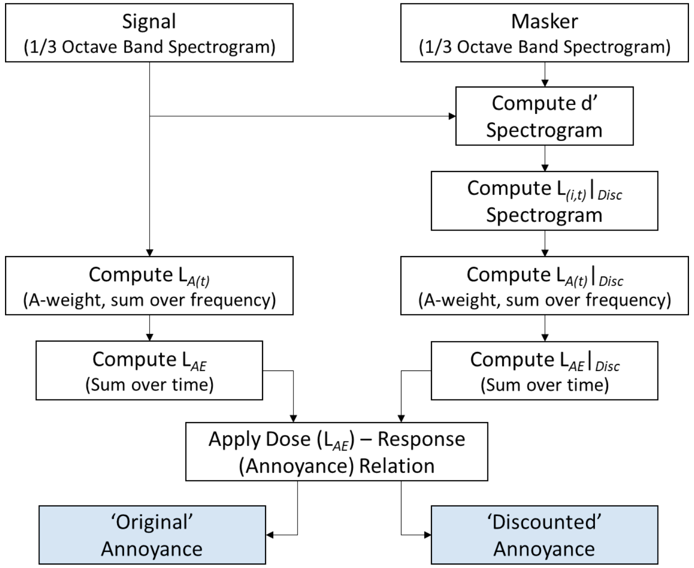
'Original' Annoyance

'Discounted' Annoyance



Single-event relationship between annoyance to small UAS and L_{AE} is a surrogate for UAM-specific relation.

Annoyance = $0.125\ L_{AE} - 3.61$



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Compute L_{AE} (Sum over time)

Compute $L_{AE}|_{Disc}$ (Sum over time)

Apply Dose (L_{AE}) – Response (Annoyance) Relation

'Original' Annoyance

'Discounted' Annoyance

	Original	City Hall (Discounted)	Central Park (Discounted)
L_{AE} (dBA)	74.04	67.82	73.15
Annoyance Rating	5.64	4.87	5.53

- Discount of L_{AE} significant for City Hall masker (> 6 dBA).
- Modest reduction in annoyance at this location.

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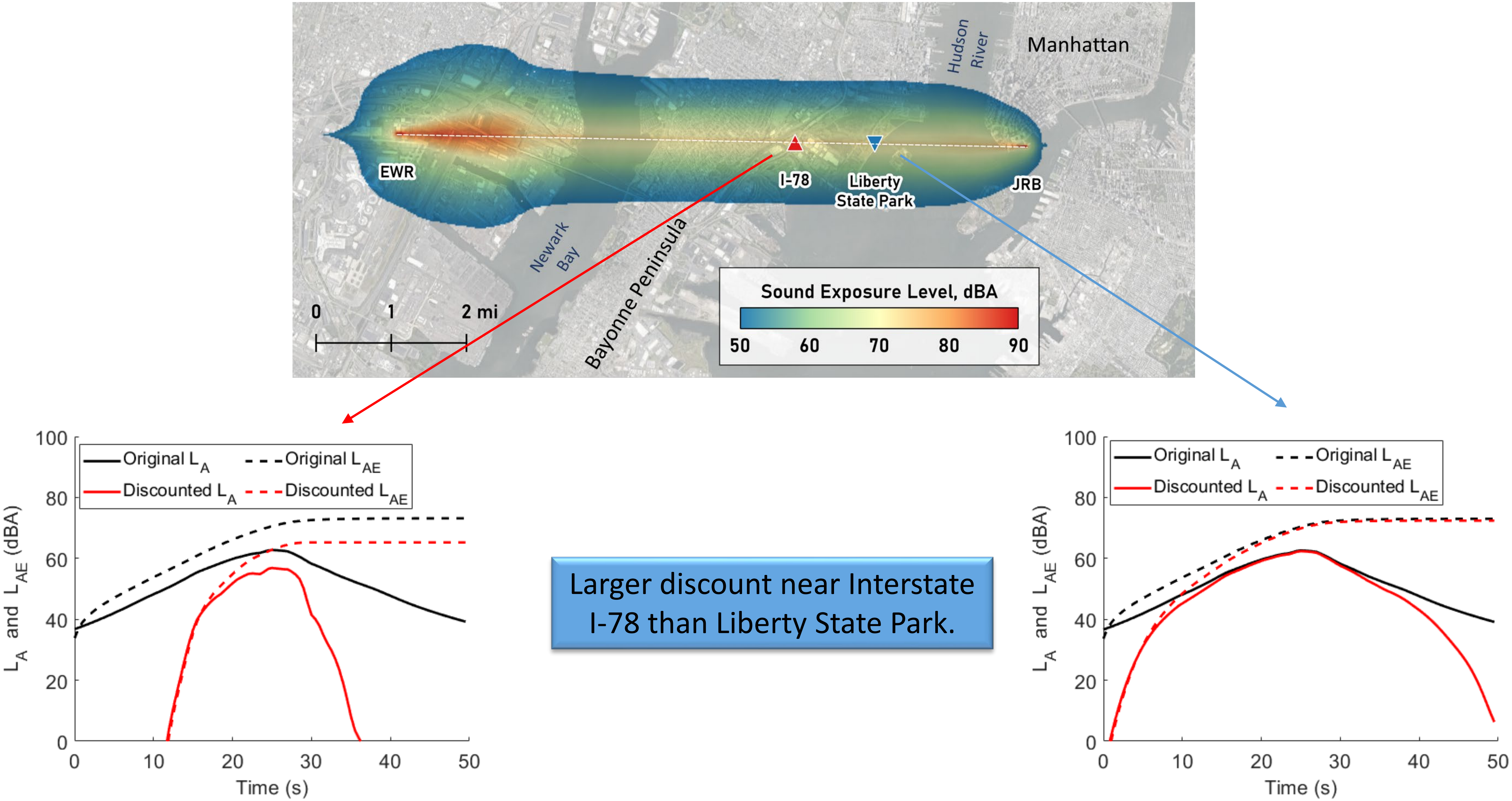
Point-To-Point Case

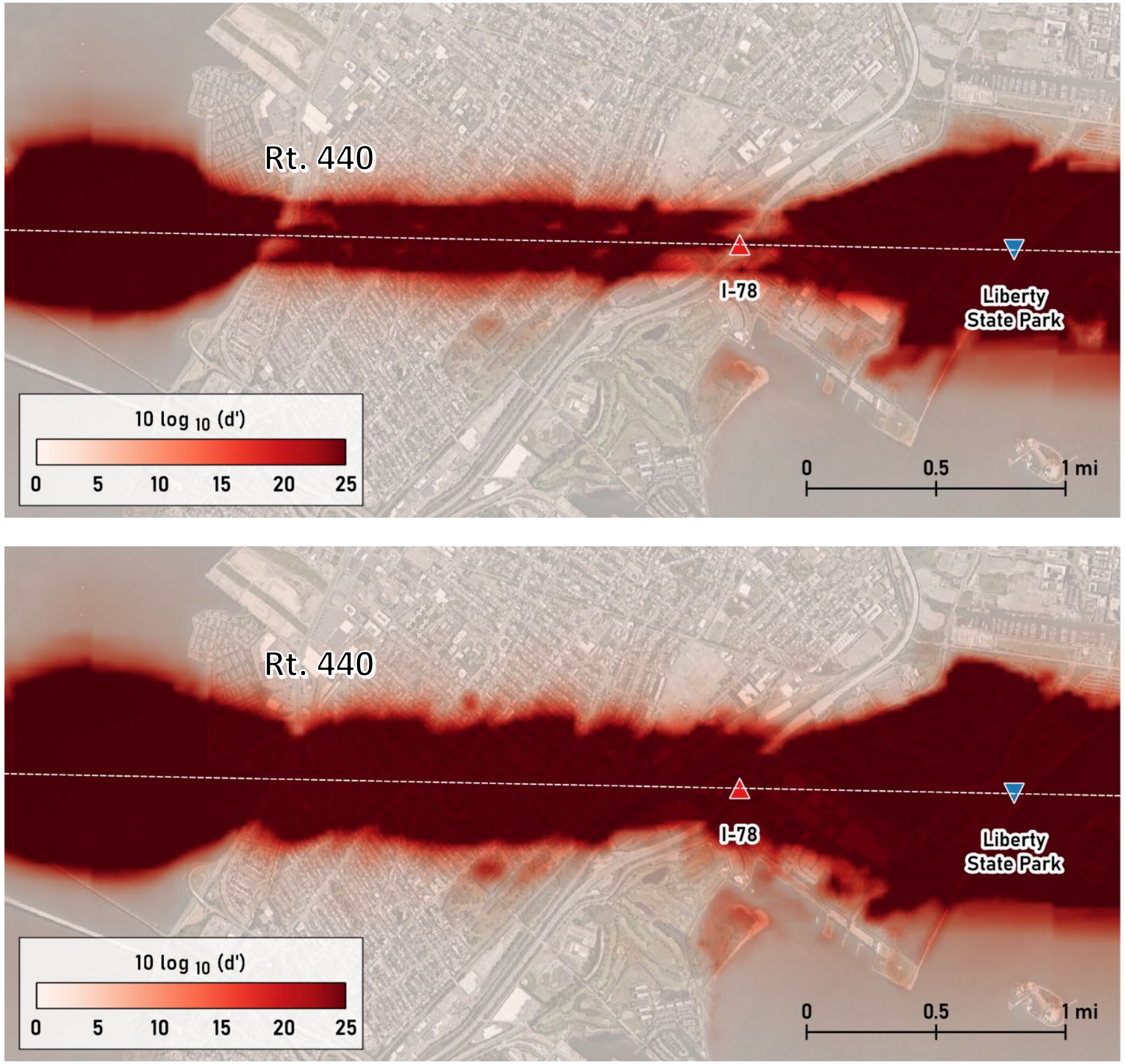


Larger discount near Interstate I-78 than Liberty State Park.

Point-To-Point Case – d' Maps

Daytime

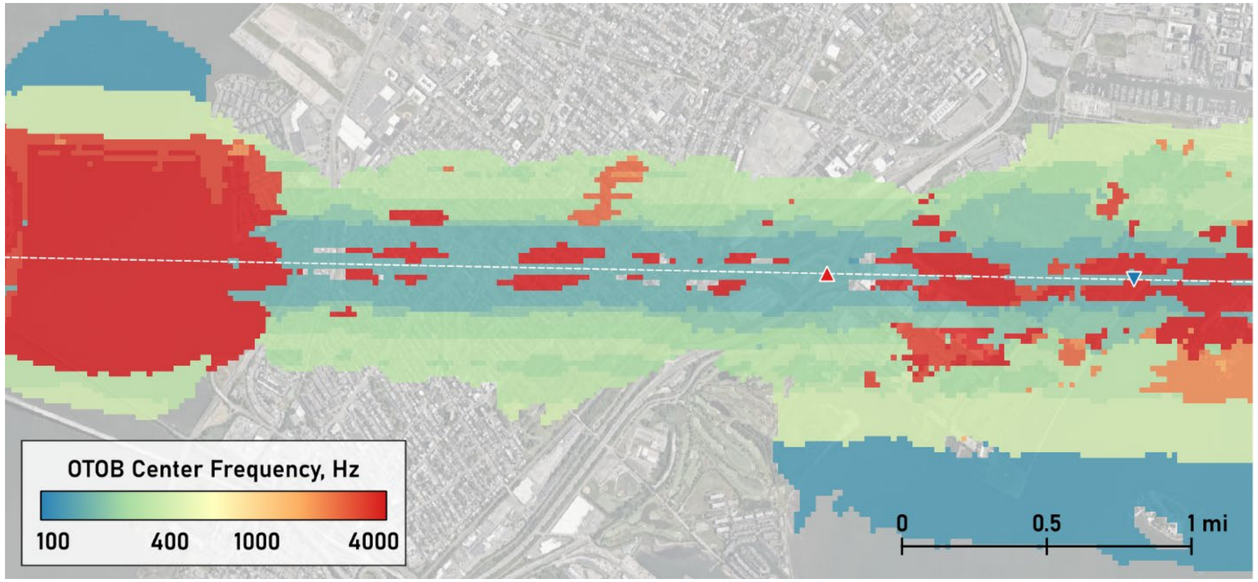
Nighttime



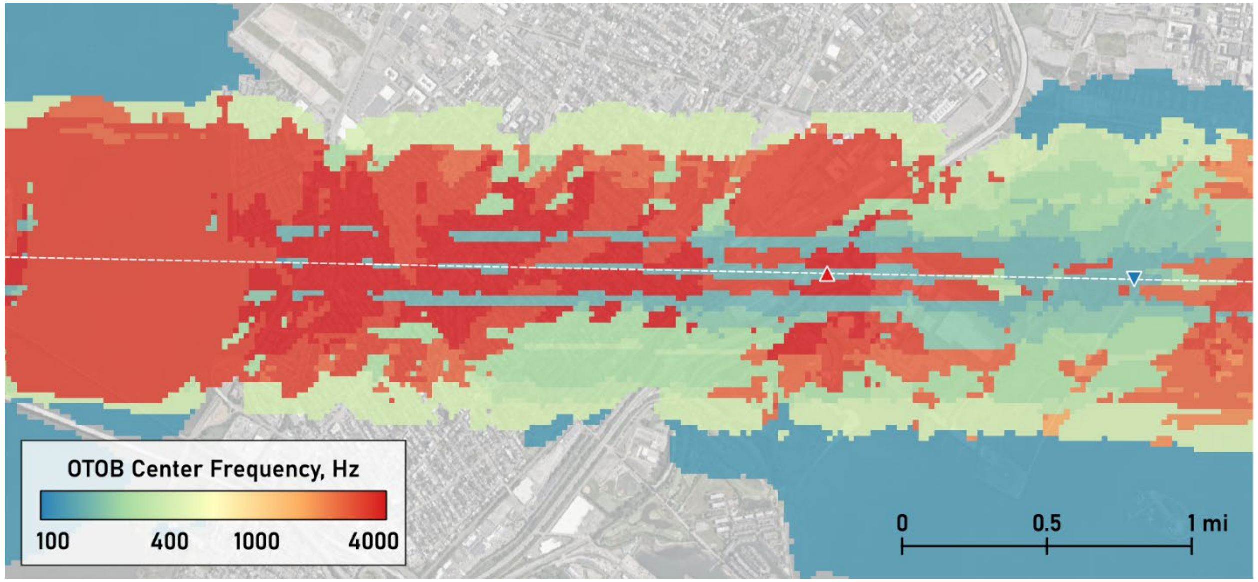
- Along Interstate I-78 and Route 440, daytime d' significantly reduced relative to nearby areas.
- Nighttime reduction in d' not as great as daytime reduction.
- At Liberty State Park, signal is audible at all times.
- Over majority of Bayonne Peninsula, signal audible over a strip about 0.5 mi (800 m) wide.

Point-To-Point Case – Maps of Frequency of Maximum d'

Daytime



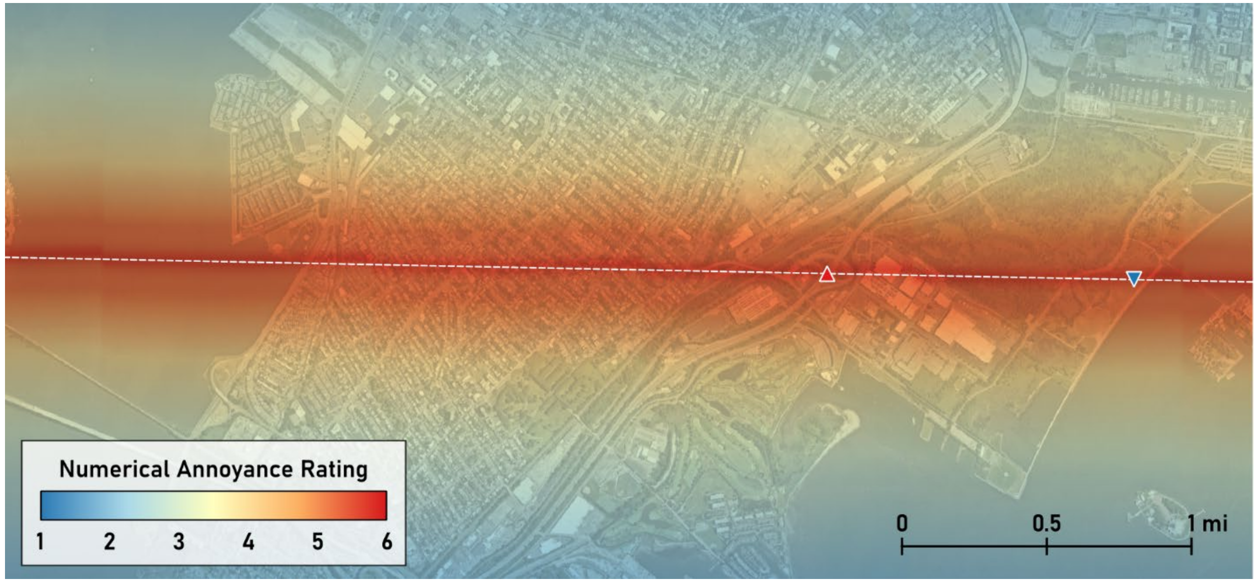
Nighttime



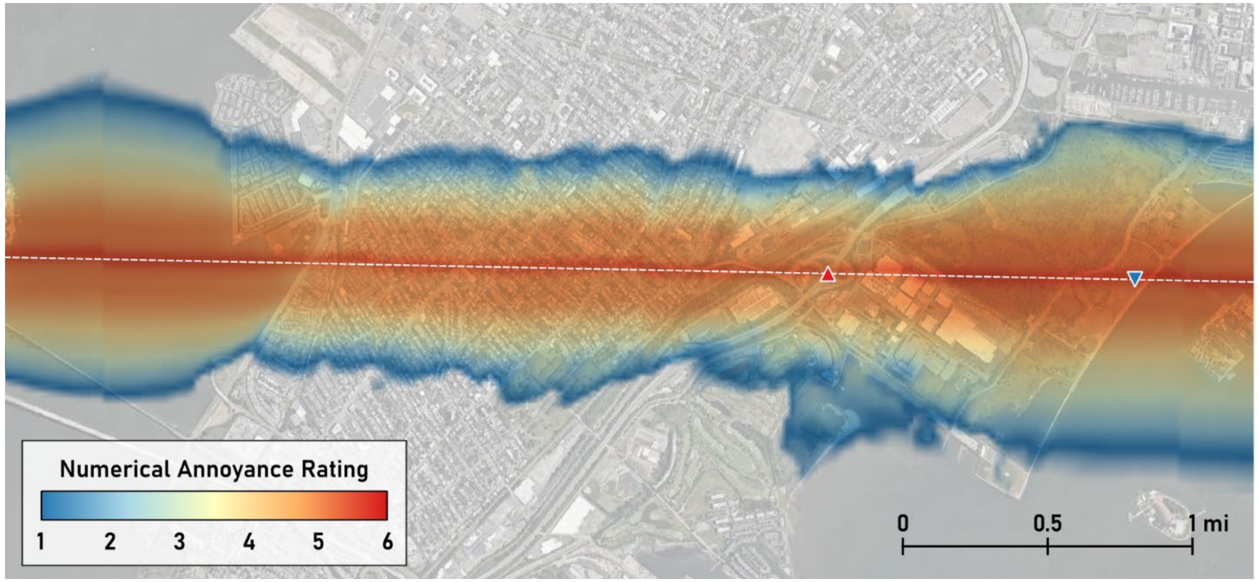
- Daytime and nighttime maps indicate detection at low-freq. low-order BPF harmonics directly under the track.
- Overall, more high frequency detection at nighttime than daytime.
- Lateral to flight path over land, frequency of detection alternates between high and low frequency.
- Over water, freq. of detection dominated by high freq. close to track and lower freq. away from track.

Point-To-Point Case – Annoyance Maps

Original



Nighttime



- Original annoyance does not vary with position along the track, but uniformly reduces from “Moderate” (6) below track to “Not at all” (2) with distance.
- Daytime annoyance slightly reduced below track and significantly reduced elsewhere except near LSP.
- Nighttime annoyance shows less reduction than daytime.

Summary and Future Work

Summary

- Method for estimating annoyance to UAM noise in the presence of masking noise exercised on two cases.
  - Overflight case demonstrated how short time scale variations in the masker affect annoyance.
  - Point-to-point demonstrated how differences between high and low ambient areas affect annoyance.

- For cases considered, annoyance lateral to track reduced relative to unmasked condition.
  - Frequency of detection lateral to track generally decreases with increasing distance.
  - Annoyance directly below flight track largely unaffected except for very high ambient conditions, e.g., near roadways. However, lateral extent of air vehicle noise >> road traffic noise.

Future Work

- Need to establish annoyance model parameters applicable to larger population.
- Consideration of range of aircraft architectures needed to evaluate fleet.
- Long-term dose-response data needed to make more meaningful annoyance estimates.

Acknowledgments

This work was supported by the NASA Aeronautics Research Mission Directorate, Revolutionary Vertical Lift Technology Project.

Development of the BRRC AMBIENT model was performed under United States Army-funded Small Business Innovation Research program contract W911W6-18-C-0028.

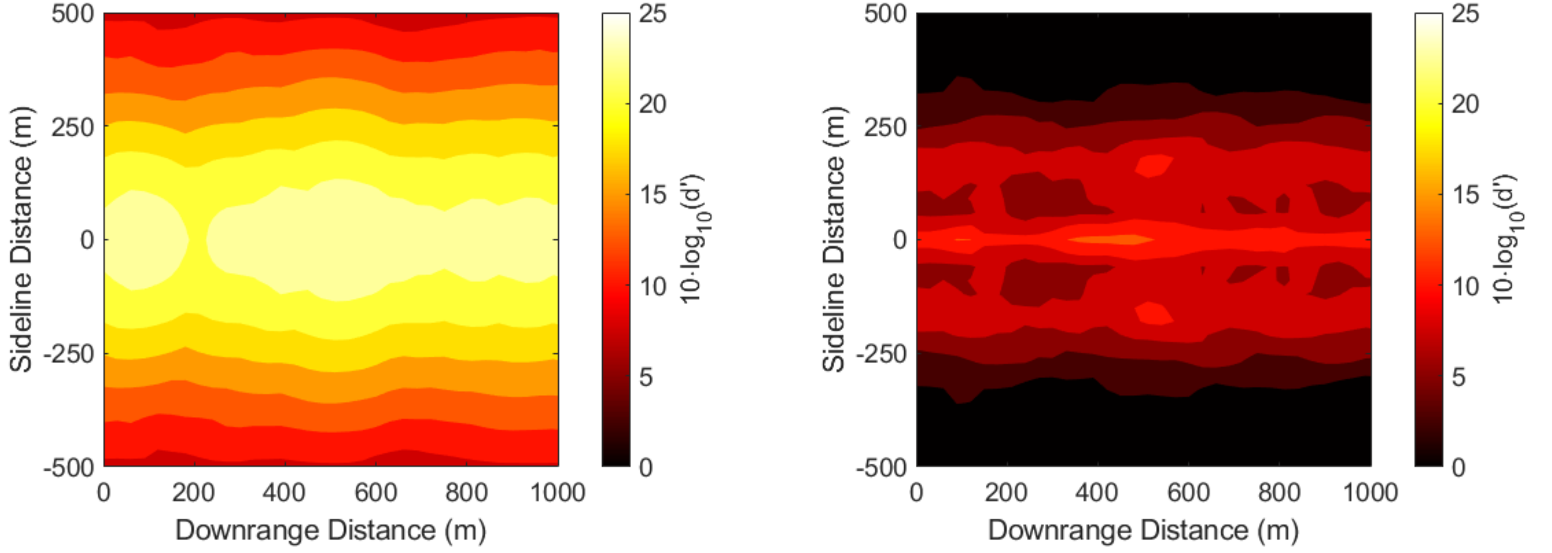
Molte Grazie

stephen.a.rizzi@nasa.gov

Backup Slides

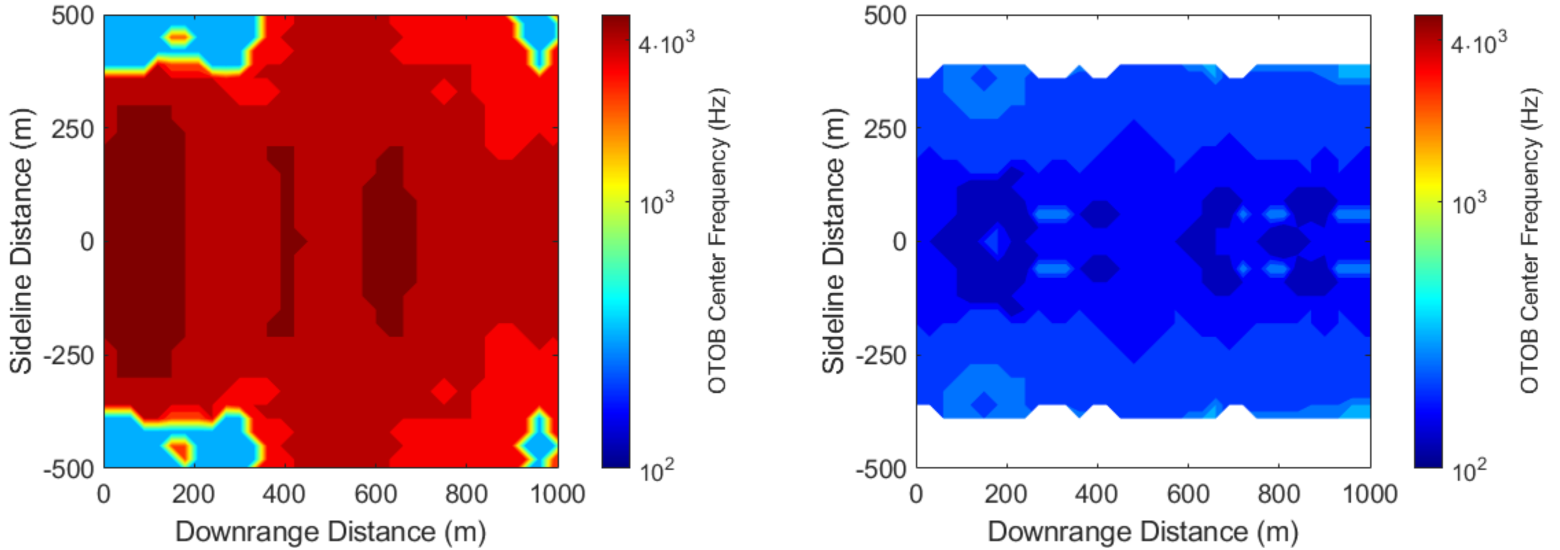
Overflight Case – Detection Contours

Central Park **City Hall**



d' Contours

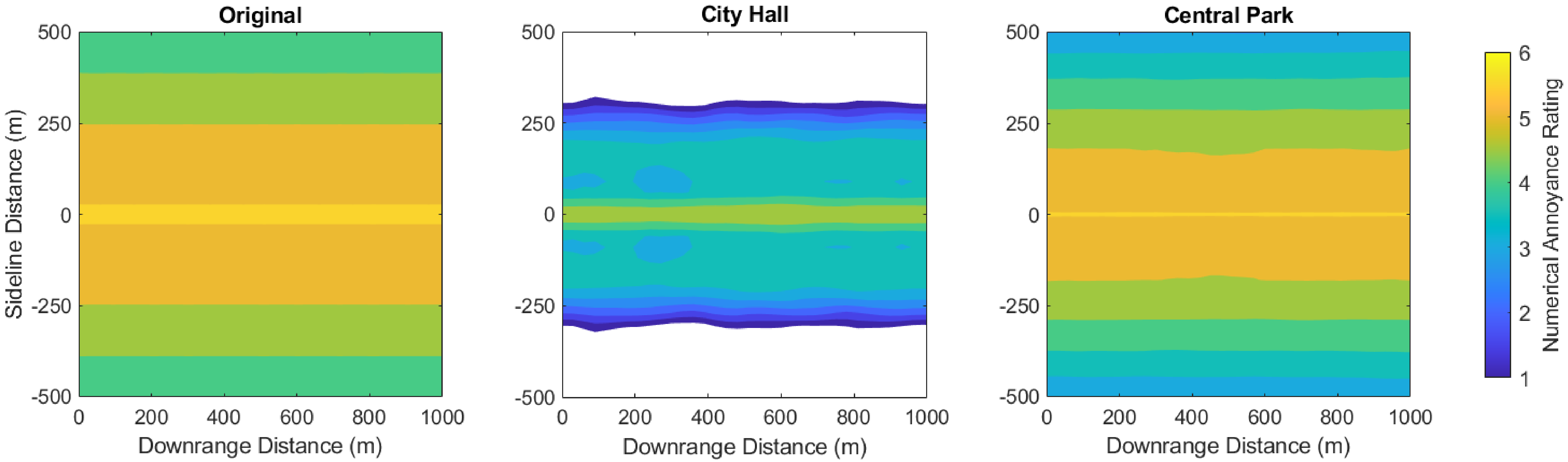
- Signal inaudible for CH at sideline distances > 300 m.
- Variation with downrange distance due to changing masking noise.



Frequency of Maximum d'

- Detection at higher frequencies for CP except at large sideline distances where atmospheric absorption reduces high freq. signal.

Overflight Case – Annoyance Contours



Annoyance spans range of “slightly annoyed” (4) distant from ground track to “moderately annoyed” (6) under the track.

Annoyance near CH reduced to “slightly annoyed” (4) under the track and drops to “not at all” at < 200 m sideline distance.

Annoyance near CP remains “moderately annoyed” (6) under the track and falls off to almost “not at all” at greatest sideline distance.