Sound Propagation Model

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Elements considered in the model

1. Geometric Divergence
2. Atmospheric Attenuation
3. Ground Attenuation
4. Distance to the closest Obstacle
5. Vertical Diffraction

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6. Horizontal Diffraction

ISO 9613 (with Joule's Report edition)

- Point source based outdoor propagation
- International standard
- Joule's Report(J H Bass, A J Bullmore, E Sloth, 1998) suggests a simplified model, and increases accuracy based on the 500m to 1000m scale
- 1-3 applied in Barbara(2014)

NMPB 2008

- Recent model
- Applied into orbisGIS NoiseModel (Bocher et al., 2019)

ISO 9613 NMPB 2008

The equivalent continuous A-weighted downwind sound pressure level

The sound pressure at one location

For all the sound sources

For all the octave bands

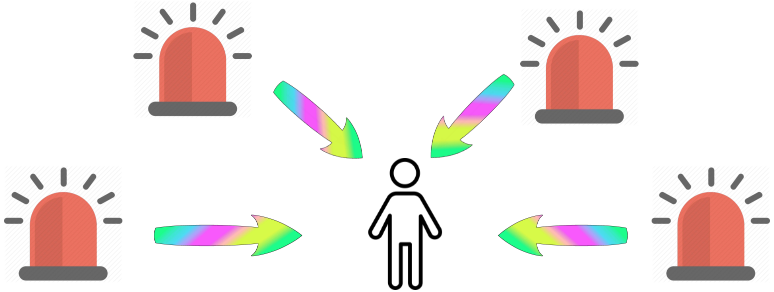
$$L_{AT}(DW) = 10\,log\left\{\sum_{i=1}^{n}\left[\sum_{j=1}^{B} 10^{0.1[L_{fr}(ij)+A_y(j)]}\right]\right\} \quad (1)$$

n the number of contributions i (sources and paths) == the number of sirens

j an index indicating the eight standard octave-band midband frequencies from 63 Hz to 8 k Hz

A_y the standard A-weighting (IEC 651)

- In this model, 125 Hz to 8 k Hz

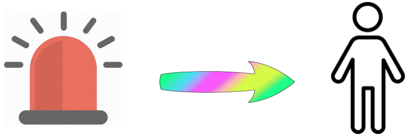


Total Noise dbSPL

125	250	500	1k	2k	4k	8k
46	28	14	44	20	11	12
46	46	27	49	51	23	14
46	31	23	29	29	14	13

ISO 9613-(2) | NMPB 2008

The equivalent continuous downwind octave-band sound pressure level at a receiver location for each point source



Total Noise dbSPL

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46	31	23	29	29	14	13

$$L_{fr}(DW) = L_W - A \quad (2)$$

L_W The **octave band sound power level**, in decibels, produced by the point sound source relative to a reference sound power of one picowatt (1 pW)

A Octave-band attenuation in decibels, that occurs during propagation from the point sound source to the receiver.

$$A = A_{div} + A_{atm} + A_{ter} + A_{obs} + A_{ver} + A_{hor} \quad (3)$$

- Octave band 63 Hz to 8 k Hz considered in ISO 9613-2 but this model considered 125 Hz to 8 k Hz due to the measured data. (8 categories to 7 categories)

Model Summary

$$L_{AT}(DW) = 10\,log\left\{\sum_{i=1}^{n}\left[\sum_{j=1}^{B} 10^{0.1[L_{fr}(ij)+A_y(j)]}\right]\right\} \quad (1)$$

A-weighted sound pressure at one receiver point is synchronization of the sound pressures from all the sound sources with the standard A-weighting. (IEC 651)

$$L_{fr}(DW) = L_W - A \quad (2)$$

The 1 to 1 interaction between a sound source and a receiver point could be calculated by the source sound pressure subtracted by attenuations.

$$A = A_{div} + A_{atm} + A_{ter} + A_{obs} + A_{ver} + A_{hor} \quad (3)$$

Attenuation factors considered are geometric divergence, atmospheric attenuation, terrain attenuation, obstacle shadow, vertical and horizontal diffraction by buildings.

$$A_{div} = [20\ log(d) + 11] \quad (4)$$

Geometric divergence is a function of distance between sound source and receiver point.

$$A_{atm} = ad/1000 \quad (5)$$

Atmospheric attenuation is determined by temperature, humidity, and distance between source and receiver.

$$A_{ter} = -3dB(A) \quad if \quad h_m \geq 1.5 \times \left[\frac{abs(h_s - h_r)}{2}\right] \quad (6)$$

Terrain attenuation is determined by average elevation of direct sound propagation path, and the elevations of receiver and source.

$$A_{obs} = 25 \quad if\ d_{obs} \leq 17 \quad (7)$$

There's obstacle shadow produced by a building obstacle. So distance from the closest building should be considered.

$$A_{ver} = 10\,log\,[3 + (C_2/\lambda)C_3 z K_{met}]\,dB \quad (8)$$

Vertical diffraction is determined by lengths of diffraction path components.

- $0 \leq A_{ver} \leq 25$

$$A_{hor} = \begin{cases} 10\,log_{10}(3 + \frac{40}{\lambda}C''\delta) & \text{if } \frac{40}{\lambda}C''\delta \geq -2 \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

Horizontal diffraction is mainly determined by the difference of lengths from diffracted path and direct propagation path.

- $0 \leq A_{hor} \leq 25$

Flow chart

$$L_{AT}(DW) = 10\,log\left\{\sum_{i=1}^{n}\left[\sum_{j=1}^{B} 10^{0.1[L_{fr}(ij)+A_y(j)]}\right]\right\} \quad (1)$$

$$L_{fr}(DW) = L_W - A \quad (2)$$

$$A = A_{div} + A_{atm} + A_{ter} + A_{obs} + A_{ver} + A_{hor} \quad (3)$$

$$A_{div} = [20\ log(d) + 11] \quad (4)$$

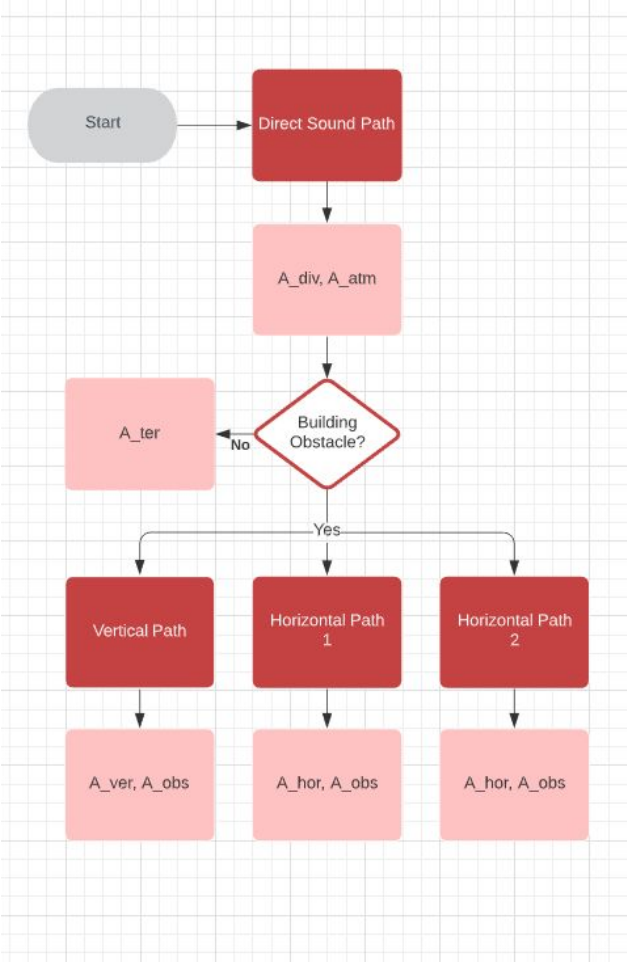
$$A_{atm} = ad/1000 \quad (5)$$

$$A_{ter} = -3dB(A) \quad if \quad h_m \geq 1.5 \times \left[\frac{abs(h_s - h_r)}{2}\right] \quad (6)$$

$$A_{obs} = 25 \quad if\ \ d_{obs} \leq 17 \quad (7)$$

$$A_{ver} = 10\,log\,[3 + (C_2/\lambda)C_3\,zK_{met}]\,dB \quad (8)$$

$$A_{hor} = \begin{cases} 10\,log_{10}(3 + \frac{40}{\lambda}C''\delta) & \text{if } \frac{40}{\lambda}C''\delta \geq -2 \\ 0 & \text{otherwise} \end{cases} \quad (9)$$



1. Geometric Divergence

$$A_{div} = [20\ log(d) + 11] \quad (4)$$

d the distance from the source to receiver, in metres

2. Atmospheric Attenuation

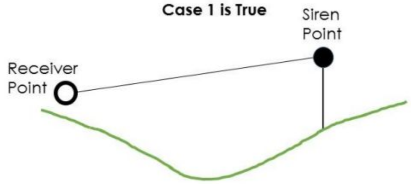
$$A_{atm} = ad/1000 \quad (5)$$

a the atmospheric attenuation coefficient,
in decibels per kilometre for each octave band at the midband frequency

- Temperature 20 celsius degree and Humidity 70% regarded

3. Ground Attenuation

Case 1. $$A_{ter} = -3dB(A) \quad if \quad h_m \geq 1.5 \times \left[\frac{abs(h_s - h_r)}{2}\right] \tag{6}$$

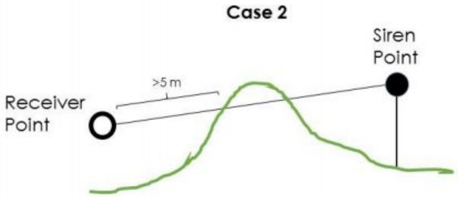


h_m the mean height above the ground of the direct line of sight from the receiver to the source

h_s and h_r are the heights above local ground level of the source and receiver respectively.

Case 2. $$A_{ter} = 2dB(A) \quad if \;\; d_{obs} > 5$$

The direct line of sight between the receiver and the source is **interrupted**, but the obstacle does not lie within 5m of the receiver.



Case 3. $$A_{ter} = 10dB(A) \quad if \;\; d_{obs} \leq 5$$

The direct line of sight between the receiver and the source is **interrupted** by a barrier that lies within around 5m of the receiver.

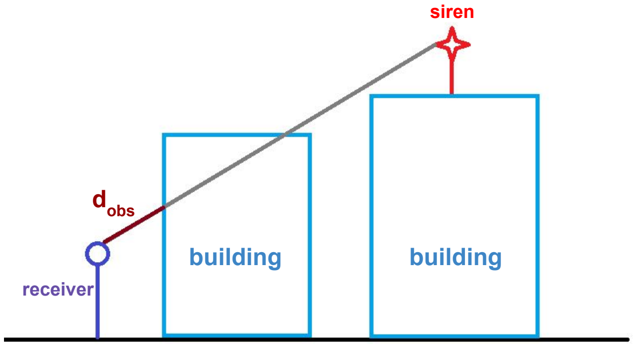
4. Distance to the closest Building

There's a minimum distance between the observer and the building for echo to be heard.

Distance between the observer and the obstacle = d
Speed of sound = v
Time after which echo is heard = t
t = 2d/v, d = vt/2

Speed of sound in air at 20 celsius degree = 340 ms^{-1}

So, for an echo to be heard distinctly,
t >= 0.1s
Then, d >= (340 ms^{-1} * 0.1 s) / 2 = 17 m



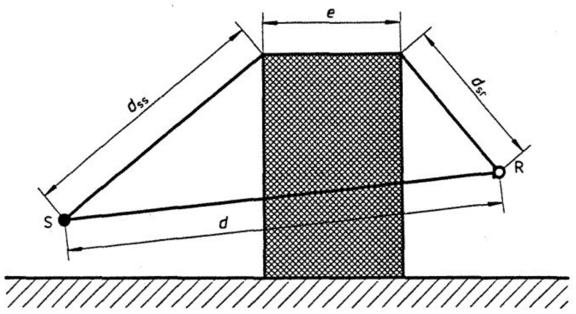
Thus, the minimum distance between the observer and the obstacle for the echo to be heard clearly should be 17 m. If the distance between the receiver point and building is less than 17, 20 dB would be reduced for each octave band. The other amount of decibels will be offset from the other image sources.

$$A_{obs} = 25 \quad if \;\; d_{obs} \leq 17 \qquad (7)$$

5. Vertical Diffraction

$$A_{ver} = 10\,log\left[3 + (C_2/\lambda)C_3\,zK_{met}\right]dB \quad (8)$$

- $0 \leq A_{ver} \leq 25$



A_{ver}	the vertical attenuation against horizontal barriers for each octave band.
C_2	equal to 20 and includes the effect of ground reflections.
C_3	for double diffraction could be calculated as $C_3 = \left[1 + (5\lambda/e)^2\right] / \left[(1/3) + (5\lambda/e)^2\right]$
λ	the wavelength of sound at the nominal midband frequency of the octave band in metres.
z	difference between the pathlengths of diffracted and direct sound, could be calculated as $z = \left[(d_{ss} + d_{sr})^2 + a^2\right]^{1/2} - d$
K_{met}	the correction factor could be calculated as $K_{met} = exp\left[-(1/2000)\sqrt{d_{ss}d_{sr}d/(2z)}\right]$
e	the distance between the two diffraction edges in the case of double diffraction.
a	the component distance parallel to the barrier edge between source and receiver, in metres.

6. Horizontal Diffraction

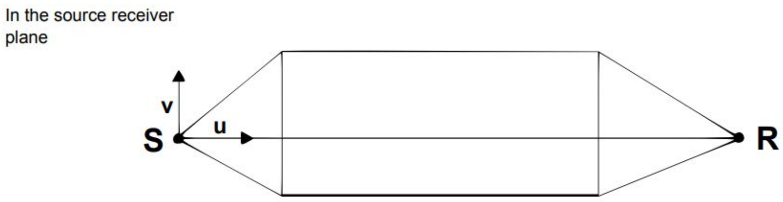


Figure 6.2: Overview of three trajectories detected in the source-receiver plane

$$A_{hor} = \begin{cases} 10\, log_{10}(3 + \frac{40}{\lambda} C'' \delta) & \text{if } \frac{40}{\lambda} C'' \delta \geq -2 \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

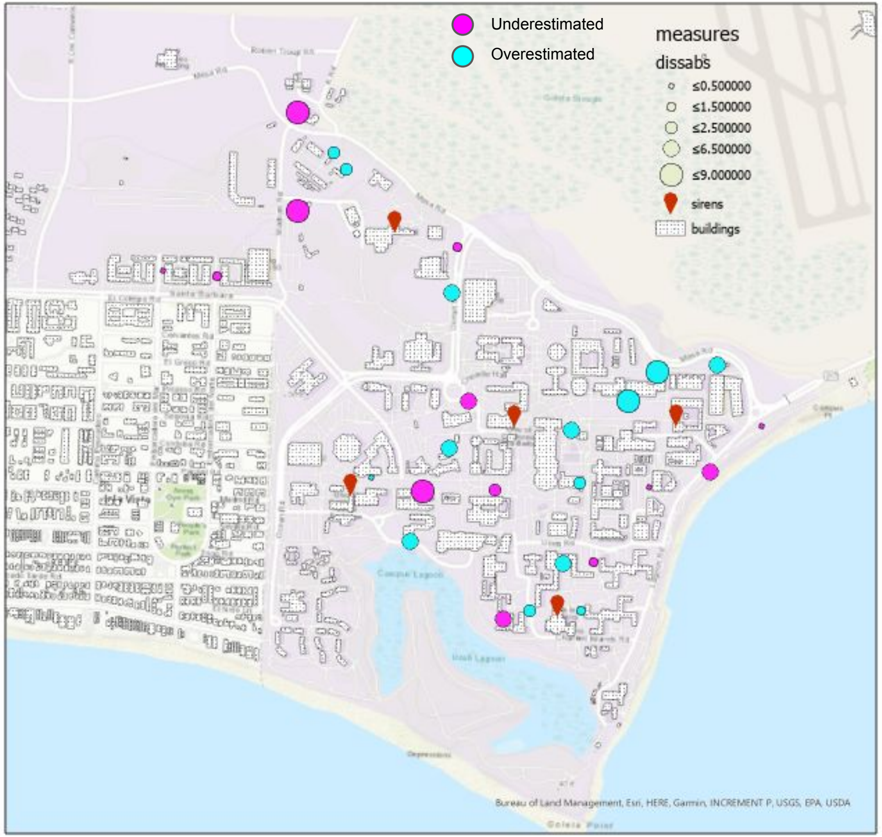
λ is the wavelength at the nominal median frequency of the third-octave band in question;
δ is the path difference between the diffracted and direct trajectories (Cf. Section 7.4.3);
C'' is a coefficient used to consider multiple diffractions: C''=1 for a single diffraction;

- $0 \leq A_{hor} \leq 25$
- Only the farthest building vertice from each direct sound propagation path was selected to build horizontal diffraction path.

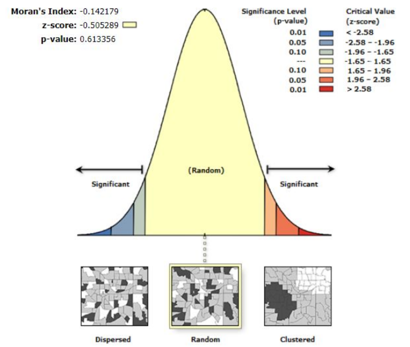
Previous Models

Goto and Murray (2020)	Spatial decay Atmospheric absorption Coherence (synthesizing effect of multiple sources)
B.Webster (2014) * no ambient noise (solved) * python source code provided * no need to consider octave bands	Spatial decay Atmospheric absorption Terrain effect (simplified) Building effect (simplified) Wind attenuation
NoiseMap (2019)	*Octave band Spatial decay Atmospheric absorption Horizontal & Vertical diffraction Terrain effect Ambient noise Coherence
SPreAD-GIS	Upperground objects not considered *Octave band Spatial decay Atmospheric absorption Terrain effect Ambient noise(optional) Coherence

Result: The residual randomly distributed



Spatial Autocorrelation Report



Given the z-score of -0.505289, the pattern does not appear to be significantly different than random.

Global Moran's I Summary

Moran's Index:	-0.142179
Expected Index:	-0.037037
Variance:	0.043298
z-score:	-0.505289
p-value:	0.613356

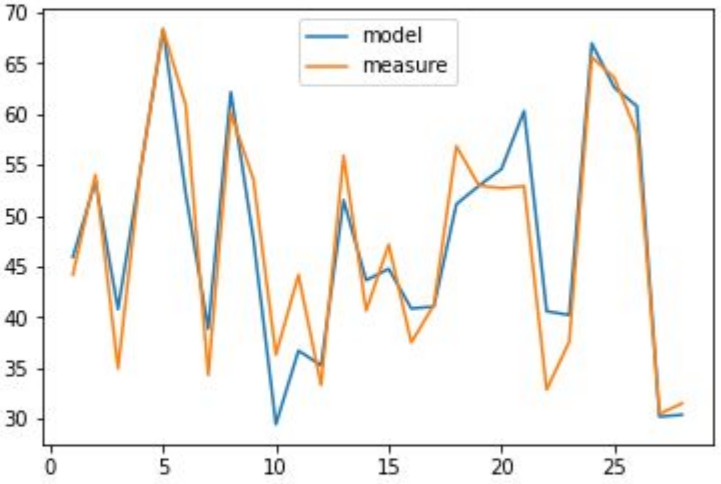
Dataset Information

Input Feature Class:	measures
Input Field:	DISS
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	True
Distance Threshold:	185.8048 Meters
Weights Matrix File:	None
Selection Set:	False

Result: estimations and measurements

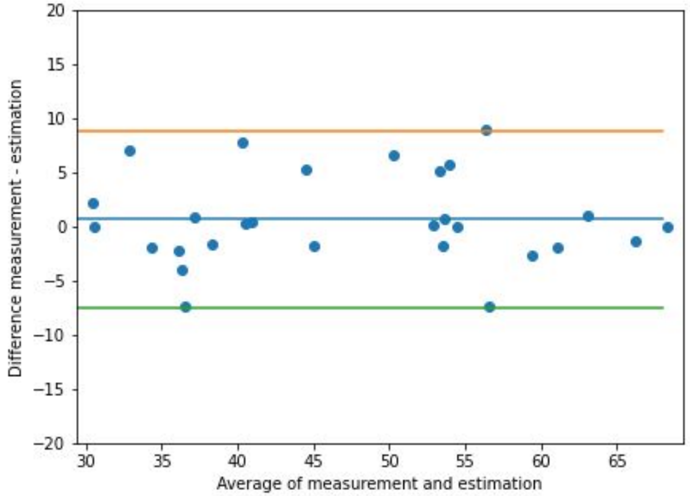
Pearson’s r: (0.93, 9.620780939909188e-13)
rmse: 4.19 dB(A)

dB(A)

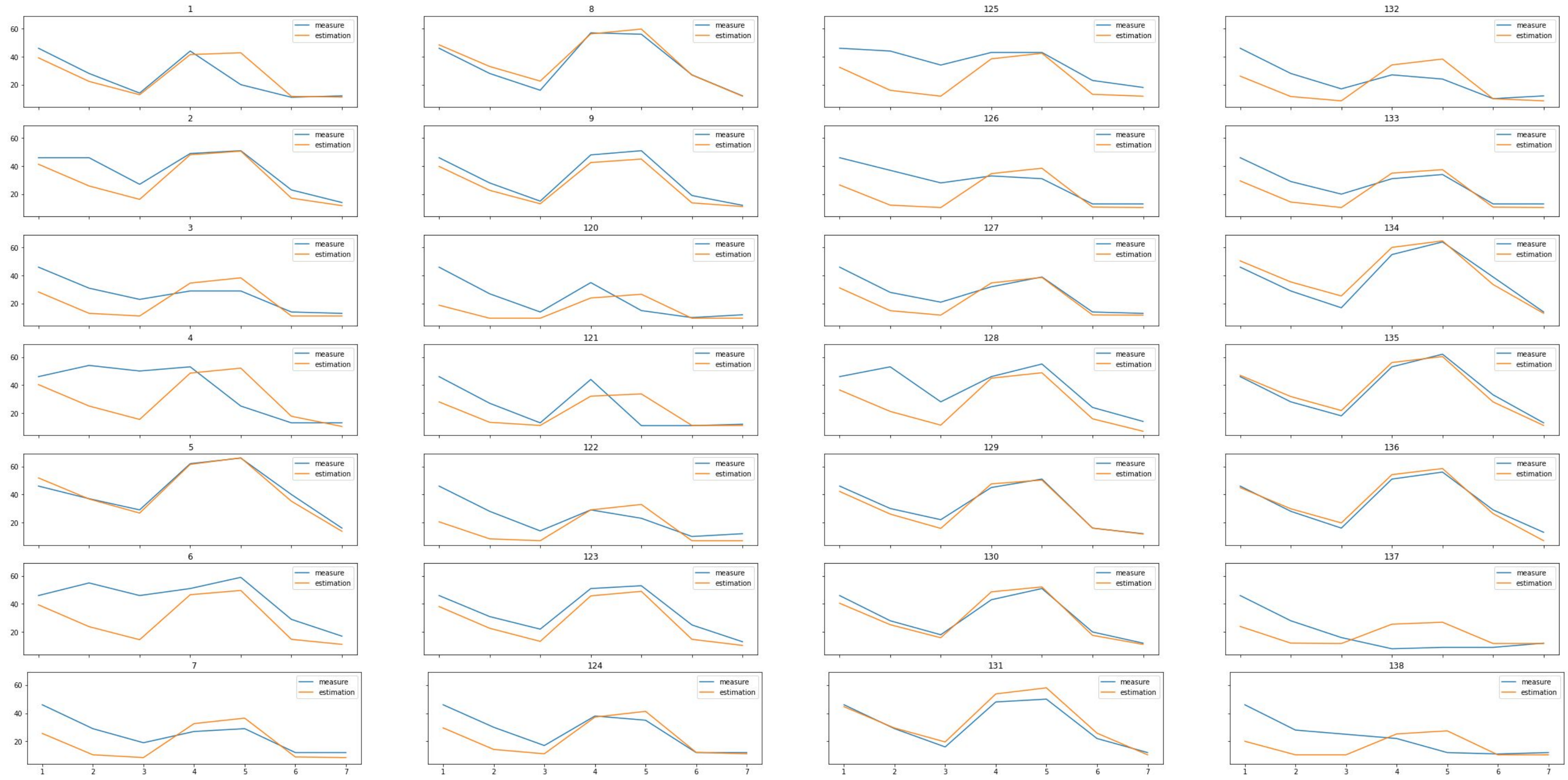


Measure Points

Mean of the differences : 0.64
Standard deviation: 4.17
CI (95%): (8.84, -7.542001910449568)



For each octave bands (125 hz, 250 hz, 500 hz, 1000 hz, 2000 hz, 4000 hz, 8000 hz)



Result

dbSPL - Sound pressure or Acoustical pressure, the local pressure deviation from the ambient (average or equilibrium) atmospheric pressure, caused by a sound wave.

OBJECTID	ID	Measured	dbSPL	Model
1	1	66.72	44.20866281	47.00423317
2	2	75.528	54.02045868	54.41906224
3	3	64.908	34.96249222	50.46263439
4	4	73.103	55.25252248	51.06140069
5	5	84.888	68.35540743	65.85512756
6	6	80.101	60.92630627	52.35244294
7	7	64.329	34.32243537	51.5302188
8	8	79.48	60.11875375	65.60375862
9	9	75.085	53.62192466	53.9016882
10	120	62.523	36.32183824	42.44696453
11	122	62.138	33.34000015	49.7480083
12	121	66.076	44.18999863	47.95781329
13	138	58.045	31.53000069	37.63549567
14	137	50.311	30.5	33.02435536
15	132	62.029	32.88999939	53.95153706
16	133	66.395	37.59000015	50.88257778
17	127	67.629	41.20999908	49.98596857
18	128	77.431	56.86000061	56.24655959
19	129	74.92	52.97999954	52.93983065
20	130	74.327	52.72000122	54.27748419
21	124	67.222	40.65999985	55.32871816
22	131	74.504	52.93000031	56.45295271
23	135	82.091	63.59999847	53.41034525
24	136	78.108	58.15000153	55.9792139
25	134	83.021	65.61000061	67.30834623
26	125	71.085	47.18000031	53.4030122
27	126	66.02	37.52999878	52.74329615
28	123	76.512	55.91999817	55.53104968
Mean		70.87603571	47.76788569	52.55157485
SD		8.254872265	11.51174103	7.244136548

dbSPL(wihout ambient noise) and Model

RMSE 9.153152789

Pearsonr (0.7305724244910341, 1.0142423049665363e-05)

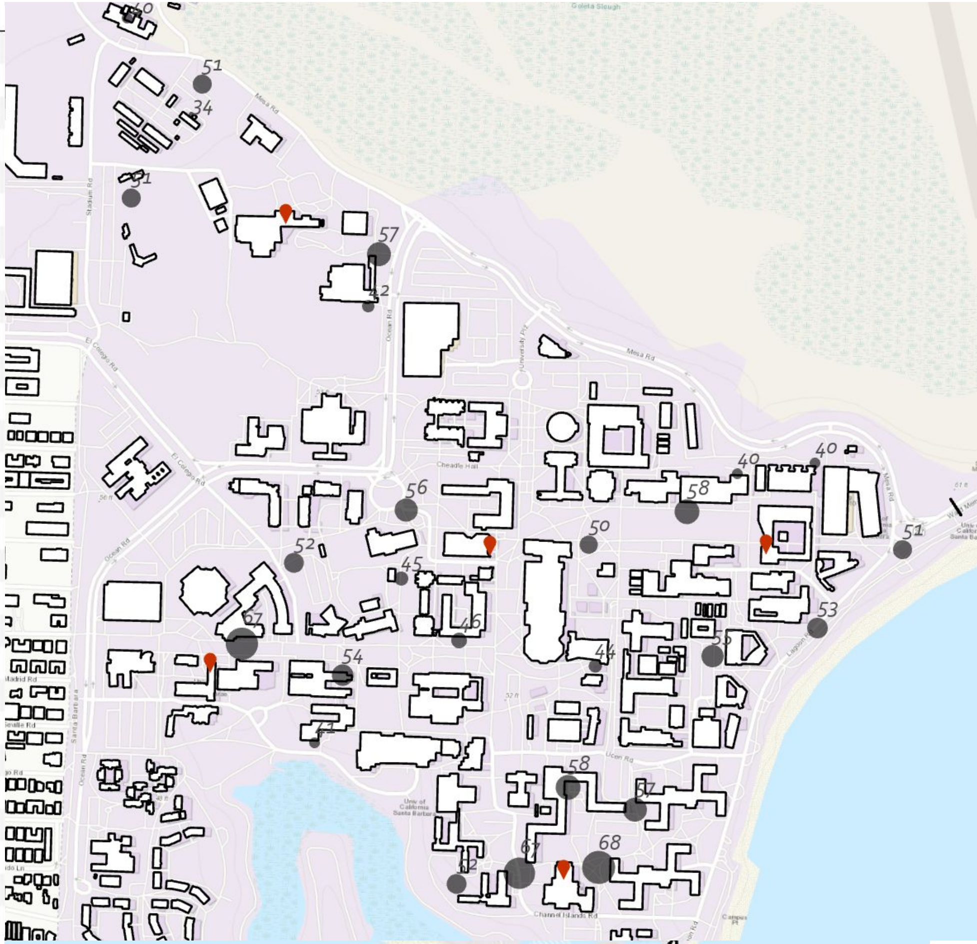
Summary of Result

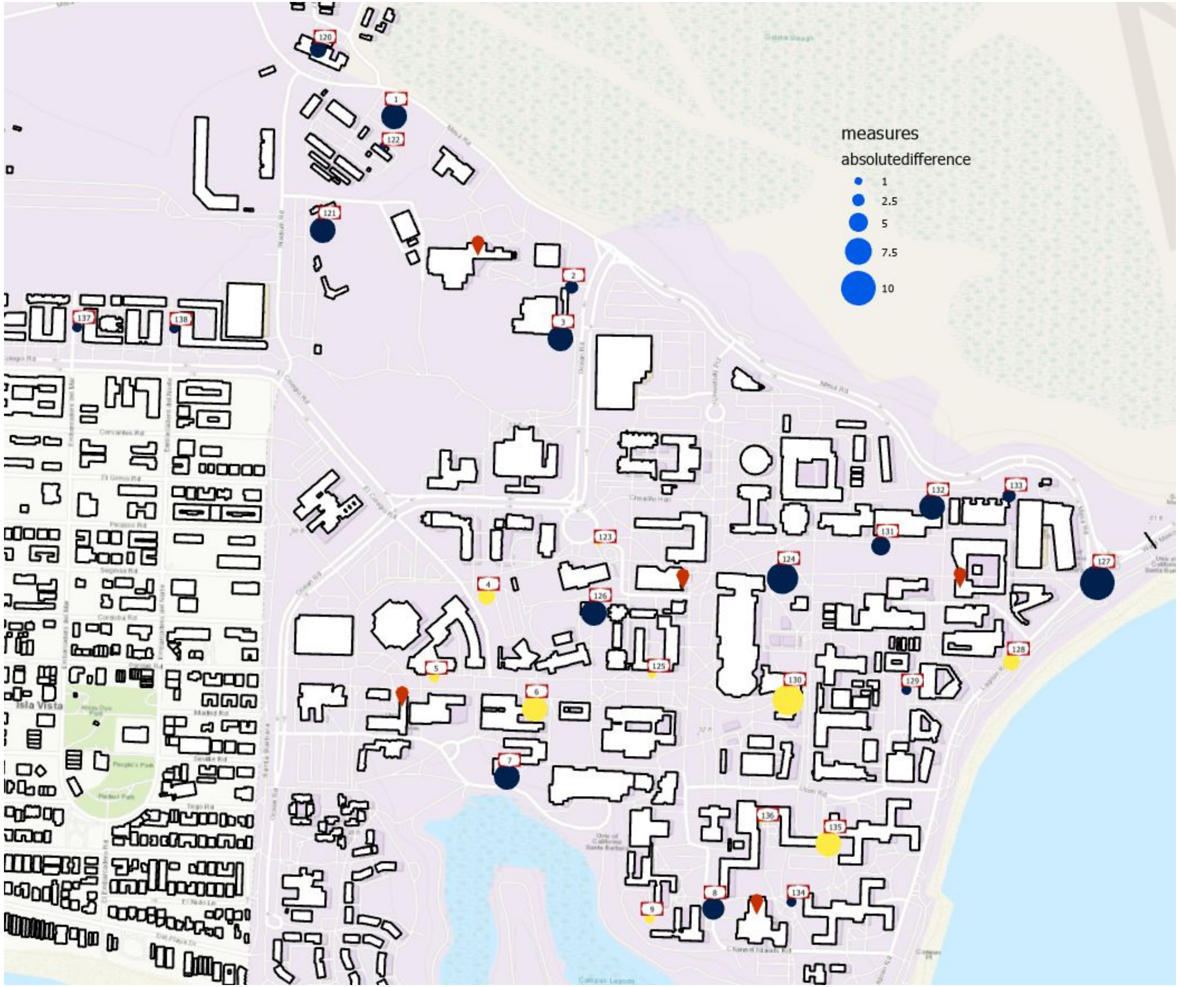
Pearson r:
0.90 (6.76e-11)

RMSE: 5.39

Sum of difference: -57.99
Mean of difference: 4.57

ID	DB	dbSPL	modi	diss
1	66.720001	44.200001	50.724515	-6.524514
2	75.528000	54.020000	57.020079	-3.000078
3	64.907997	34.959999	42.313442	-7.353443
4	73.102997	55.250000	51.624327	3.625673
5	84.888000	68.360001	66.766598	1.593402
6	80.100998	60.930000	53.590818	7.339183
7	64.329002	34.320000	40.877180	-6.557181
8	79.480003	60.119999	66.505331	-6.385332
9	75.084999	53.619999	51.776821	1.843178
120	62.522999	36.320000	40.381472	-4.061473
122	62.138000	33.340000	34.334343	-0.994343
121	66.075996	44.189999	51.227110	-7.037111
138	58.044998	31.530001	34.019930	-2.489929
137	50.311001	30.500000	32.769507	-2.269507
132	62.028999	32.889999	40.160477	-7.270478
133	66.394997	37.590000	40.361024	-2.771024
127	67.628998	41.209999	50.859214	-9.649215
128	77.431000	56.860001	53.220734	3.639267
129	74.919998	52.980000	55.099862	-2.119863
130	74.327003	52.720001	44.017146	8.702855
124	67.222000	40.660000	50.062042	-9.402043
131	74.503998	52.930000	58.168185	-5.238185
135	82.091003	63.599998	56.785834	6.814164
136	78.108002	58.150002	57.775818	0.374183
134	83.021004	65.610001	68.059759	-2.449758
125	71.084999	47.180000	46.443940	0.736060
126	66.019997	37.529999	45.021600	-7.491601
123	76.512001	55.919998	55.519970	0.400028



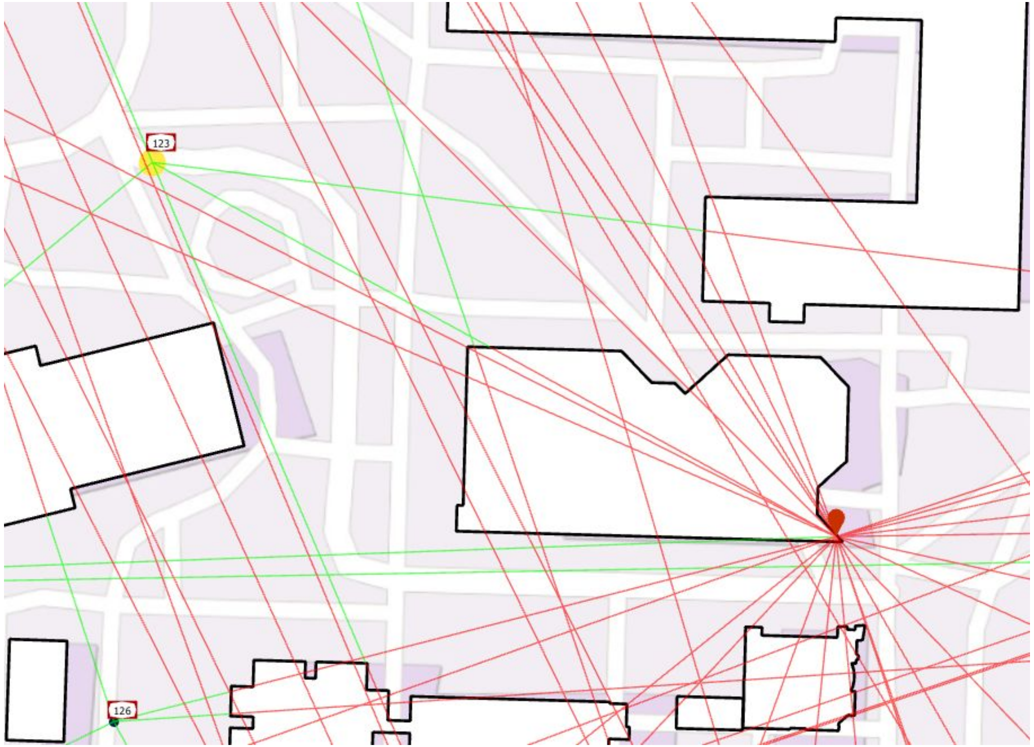


Difference Map

- Size: absolute value of difference
- Yellow: underestimated
- Blue: overestimated

Because one **building** was taken into account for diffraction, and the **reflection from image sources** was not taken into account.

Strong Point



Receiver point's sound estimation is from all the other siren points.

And each siren's effect will be calculated.

Each pair of siren-receiver interaction could be saved and directly used for optimization models.