Atmospheric Sound Propagation: Decibel levels etc.

Peter Taylor, April 2021

dB SPL (sound pressure level) – for sound in air and other gases, relative to 20 micropascals (μPa), or 2×10^{-5} Pa, approximately the quietest sound a human can hear. An RMS sound pressure of one pascal corresponds to a level of 94 dB SPL.

How loud is too loud?

Know which noises can cause damage. Wear hearing protection when you are involved in a loud activity.

- **85 dB(A)**
  Regular and prolonged exposures to noise at or above 85 dB(A) (averaged over 8 hours per day) are considered hazardous.
- **100 dB(A)**
  Regular and prolonged unprotected exposure of more than 15 minute per day risks permanent hearing loss.
- **110 dB(A)**
  Regular and prolonged unprotected exposure of more than 1.5 minutes per day risks permanent hearing loss.

By Chuck Kardous - NIOSH, Public Domain, https://commons.wikimedia.org/w/index.php?curid=70561920

Examples of noise levels

- **194 dB** Loudest possible tone
- **180 dB** Rocket launch
- **165 dB** 12-gauge shotgun
- **140 dB** Jet engine at takeoff
- **120 dB** Ambulance siren
- **119 dB** Pneumatic percussion drill
- **114 dB** Hammer drill
- **108 dB** Chain saw
- **108 dB** Continuous miner
- **105 dB** Bulldozer, spray painter
- **103 dB** Impact wrench
- **98 dB** Hand drill
- **96 dB** Tractor
- **93 dB** Belt sander
- **90 dB** Hair dryer/power lawn mower
- **80 dB** Ringing telephone
- **60 dB** Normal conversation

Noise – blowing in the wind?

The decibel is commonly used in acoustics as a unit of sound pressure level.

$$L_p = 20 \log_{10}\left(\frac{p_{\mathrm{rms}}}{p_{\mathrm{ref}}}\right)\ \mathrm{dB}$$

Where prms is the root mean square of the measured sound pressure and pref is the standard reference sound pressure of 20 micropascals in air – from Wikipedia.
Doubling p_{rms} increases L_p by 6 dB.

In a geometrical acoustics model of sound propagation along a ray, the equation for the decibel sound pressure level at a receptor, L_p, is presented by Lamancusa and Daroux (1993, hereafter L&D) as

$L_p = L_w$ - **20 $\log_{10} d$** - A_{ground} - $A_{refraction}$ - $A_{absorption}$ + 10 $\log_{10} (W_{ref} \rho c/(4\pi P_{ref}^2))$ (1)

Here L_w is the decibel sound power level of a monopole source, emitting uniformly in all directions (4π steradians) and the final term in Eq. (1) scales the sound pressure by reference pressure and power levels or rlse scalings are assumed and -10 $\log_{10}(4\pi)$ = -11 dB

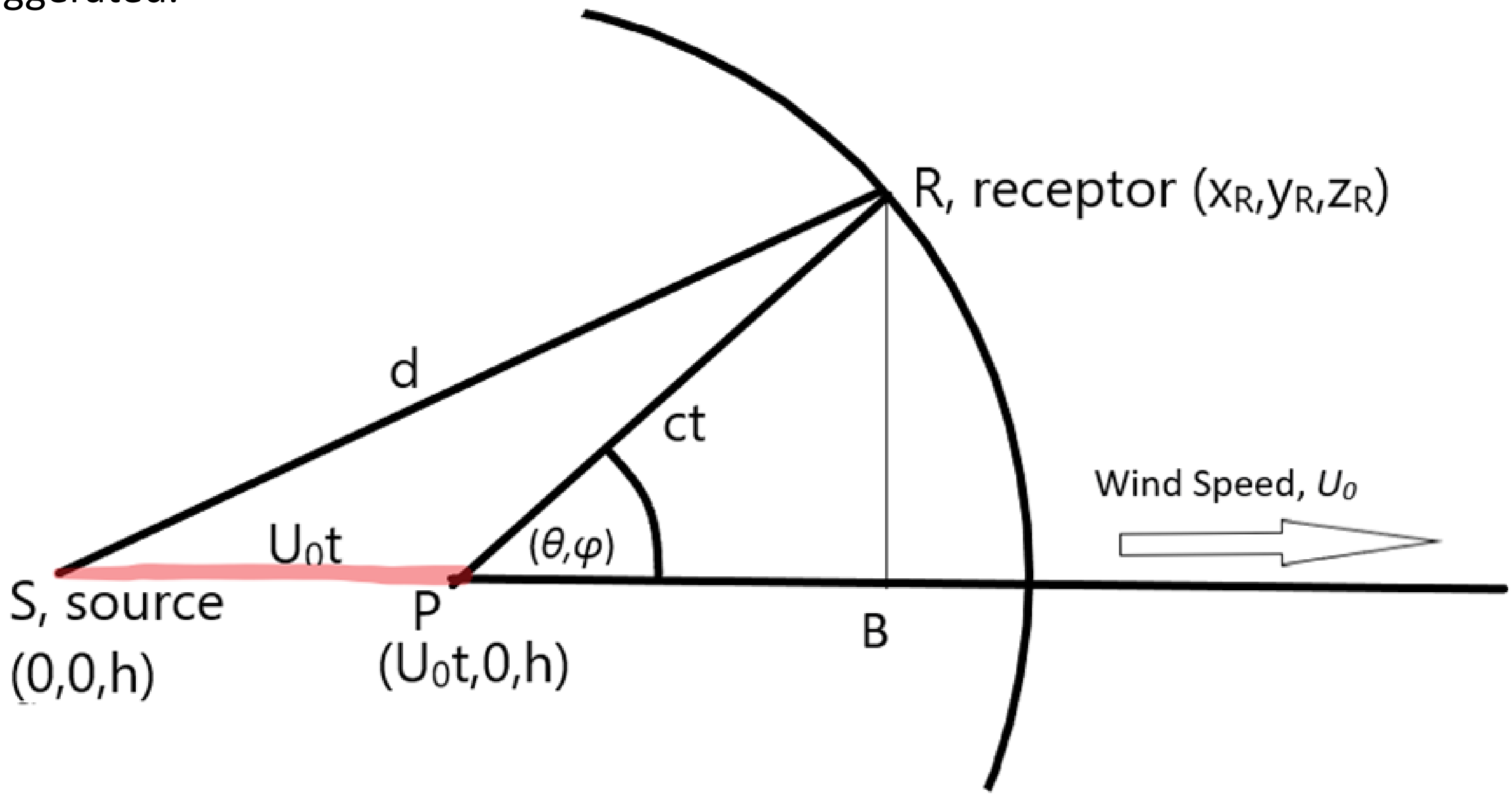
The dominant loss term is that due to spherical spreading, ($-20 \log_{10} d$). Here Lamancusa & Daroux state that d is the distance between the source and the receiver (m) but we would argue, based on Fig 1, that, if there is wind, this loss should be computed based on the distance travelled in the moving fluid rather than simply the separation distance.

L&D also state: Sound propagation in a moving medium : A common simplification applied to account for wind gradients is to add or subtract (depending on upwind or downwind conditions) the horizontal wind velocity $U(\underline{x})$ (m/s) as a scalar quantity from the sound speed due to temperature T (°C) by

$$c = 20.05\,(T+293.15)^{1/2} + U(\underline{x}) \text{ (m/s)}.$$

But it is not clear how that is applied.

Suppose there is a wind, U_0, blowing past the source, S. If a sound pulse leaves at time zero, and spreads spherically where is it after time t? Note c >> U_0 so figure exaggerated.



Is the spreading loss 20 $\log_{10}$ d or 20 $\log_{10}$ ct ? Typical d might be 550 m, **20 $\log_{10}$(550) = 54.8dB.** At 10 m? Also what happens to sound frequency?

The effective azimuth and zenith angles of the ray, relative to the source, are then modified to become,

$$\vartheta_R = \text{atan2}\,(c \sin\varphi \sin\vartheta,\ U_0 + c \sin\varphi \cos\vartheta) \tag{4}$$

$$\varphi_R = \pi/2 + \text{atan2}\,(-c \cos\varphi,\ ((U_0 + c \sin\varphi \cos\vartheta)^2 + (c \sin\varphi \sin\vartheta)^2\ )^{1/2}) \tag{5}$$

Based on the receptor location that we are interested in we can determine the required ϑ_R, φ_R angles. Then it is the inverse relationship to determine ϑ and φ for rays that would strike a particular target receptor that is needed for our ray tracing. We can determine ϑ_R, φ_R from the S and R coordinates and then,

$$\vartheta = \text{atan2}\,(d \sin\vartheta_R \sin\varphi_R,\ d \cos\vartheta_R \sin\varphi_R - U_0 t) \tag{6}$$

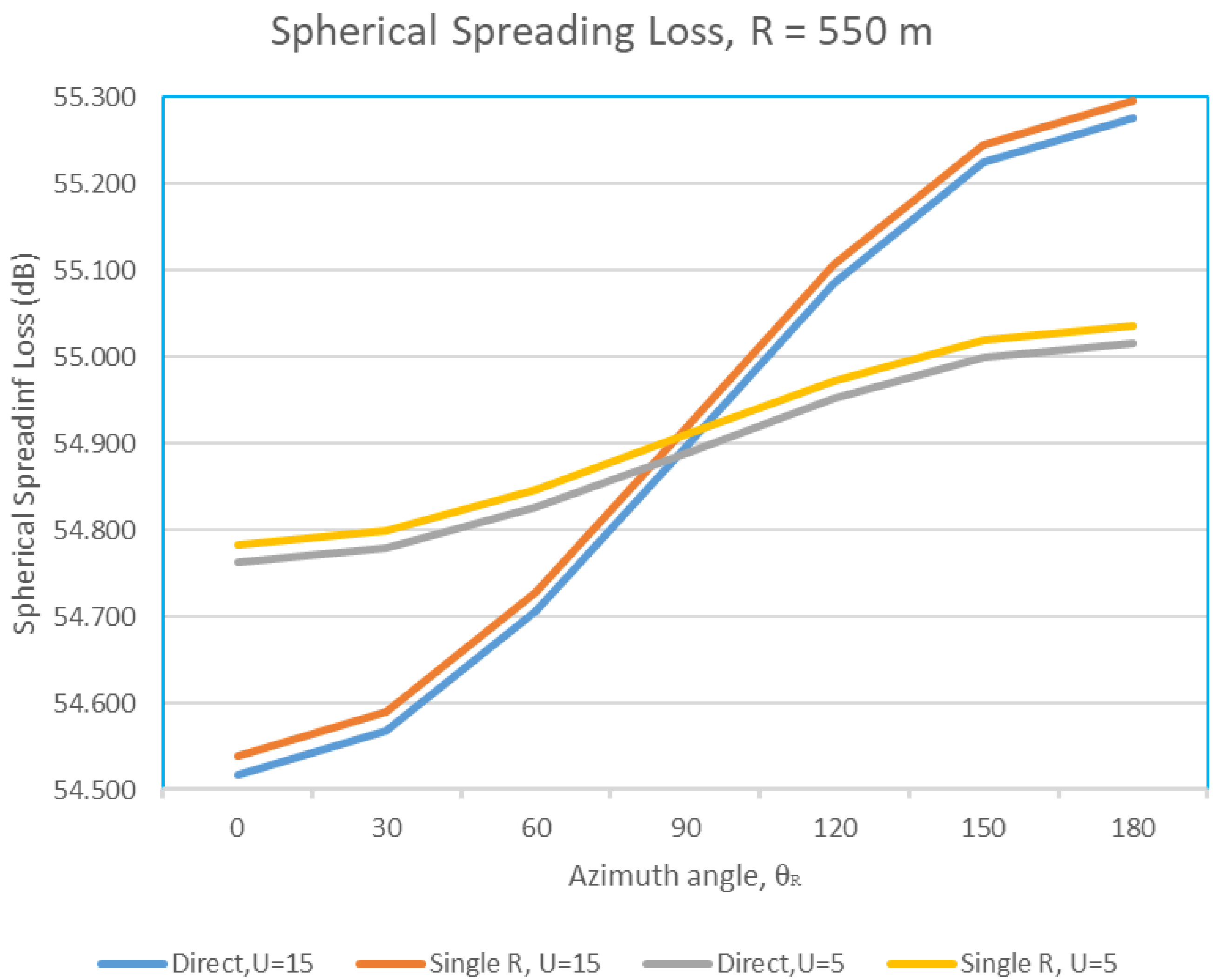
$$\varphi = \pi/2 + \text{atan2}\,(-d \cos\varphi_R,\ ((d \cos\vartheta_R \sin\varphi_R - U_0 t)^2 + (d \sin\vartheta_R \sin\varphi_R)^2\ )^{1/2}) \tag{7}$$

In the constant U, constant c case we can determine t by working in the plane containing S, P and R. We can define the point B $(x_R, 0, h)$ on the x axis and angles ψ (BPR), ψ_R (BSR) and δ (SRP) as defined for Fig 1. Applying the sine rule to triangle SPR we have

$$U_0 t/\sin\delta = ct/\sin\psi_R \quad \text{and so} \quad \sin\delta = (U_0/c)\sin\psi_R \tag{8}$$

and $\sin\psi_R = s_R/d$ where $s_R^2 = y_R^2 + (z_R-h)^2$. Then δ can be determined, $\psi = \psi_R + \delta$, $t = (s_R/\sin\psi)/c$, and ϑ and φ obtained from Eq. 6 and 7. Caution is needed when 90 °< ϑ < 270° when BSR = $\pi - \psi_R$.

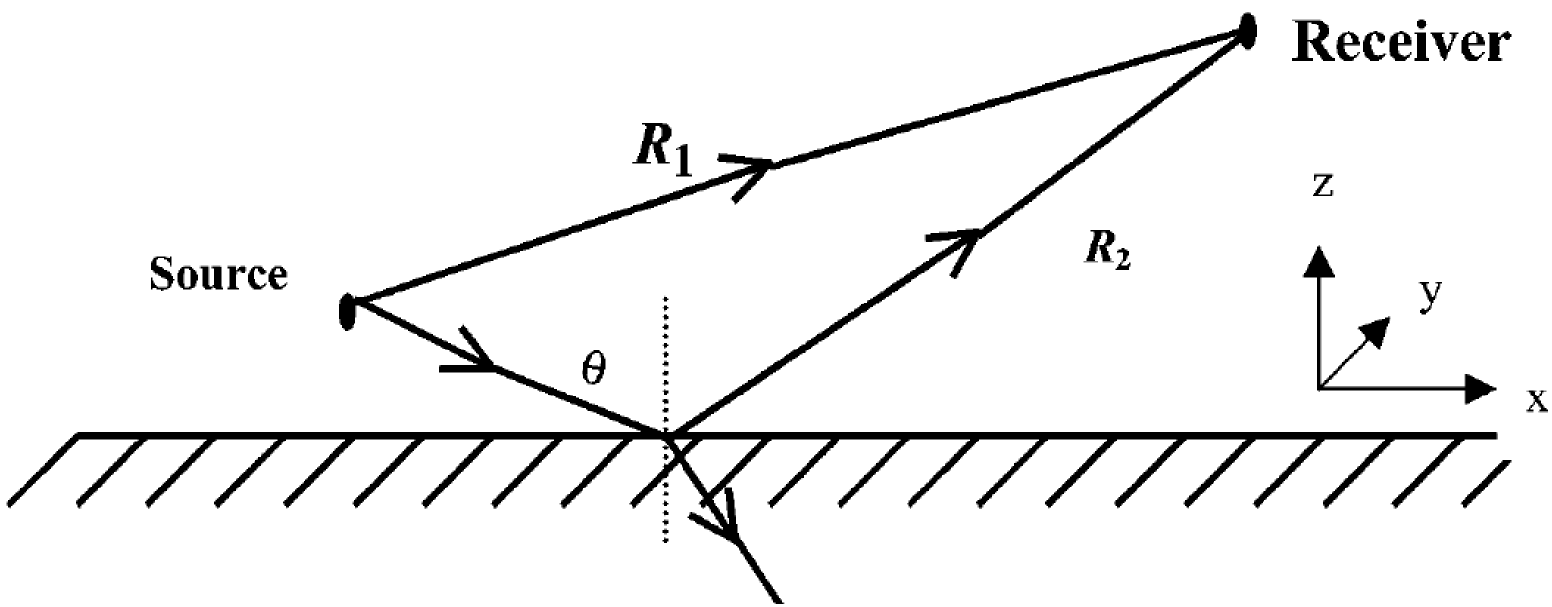
Fig. 2 Spherical spreading loss (20 $\log_{10}$ ct) for a source at 80m, receptor at 4.5 m, 550 m away (R, horizontally). Wind speeds U_0 = 5 and 15 ms^{-1} and $c \approx 340$ ms^{-1}. (T=15°C). Direct rays and rays with a single, perfect reflection.



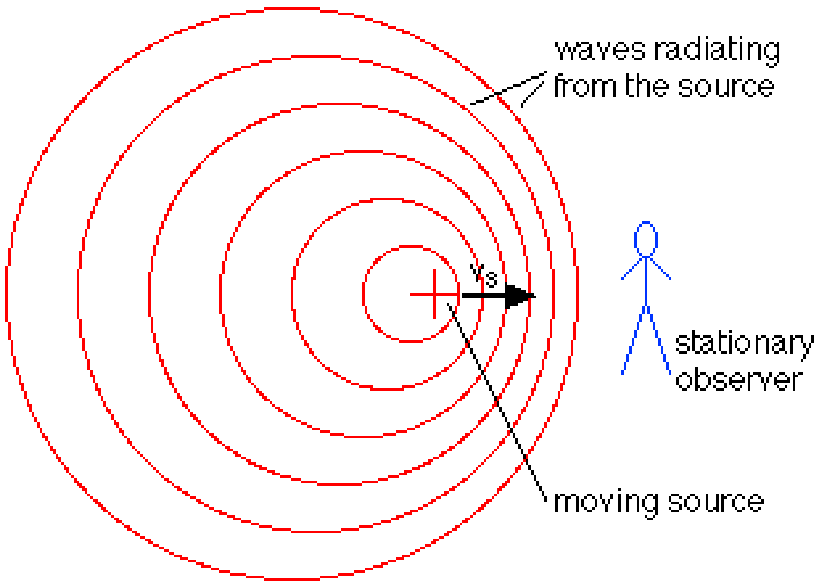
Other issues, reflection and refraction, atmospheric absorption.

Reflection from the ground

When two rays reach the receptor they can interfere constructively or destructively depending on the phases of the two rays, which will depend on their frequency and the travel times of the two rays. The reflected ray amplitude will depend on the nature of the reflecting surface and can be represented by a complex spherical wave reflection coefficient.



Doppler Shift



Usually discussed in terms of moving source or receiver, but if the medium is moving?

Or in a frame reference moving with the wind the source is moving away from the receiver and the receiver is moving towards the source. What does that do to the frequency?

I am not absolutely sure but with the source and receiver moving together then I think…..

$$f = [(c+V)/(c+V)]\ f_0 = f_0\text{, so no shift!}$$

But check out https://www.acs.psu.edu/drussell/Demos/doppler/doppler.html

Refraction loss, or gain

Ray paths can be bent by changes in U or c. Effect computed along ray tubes bu Blokhintzev invariant.

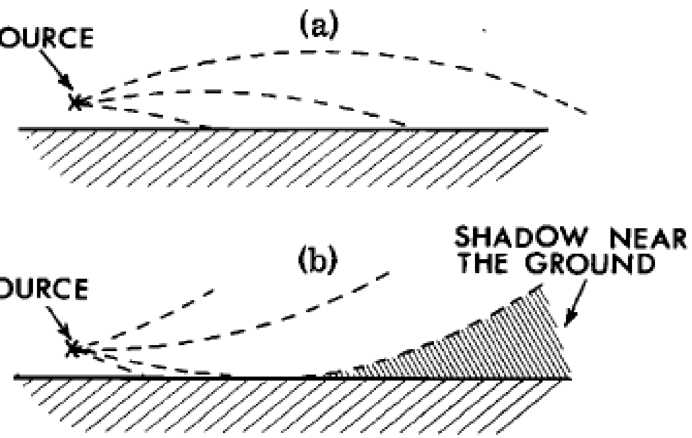


FIG. 14. (a) Refraction downward—inversion or downwind propagation. (b) Refraction upwards—lapse or upwind propagation.

Review of noise propagation in the atmosphere

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