MG Acoustics

Sound propagation:
Review and tutorial

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Fall 2013 Modelling Conference.

Outline

- Brief historical perspective
- Main propagation features
- Engineering models

Historical perspective

- **Concern about noise did not start with the advent of jet aircrafts…**

- **4000 BC - …the Great Flood was the punishment of the people for making too much noise, and so disturbing the tranquility of the gods (*Epic of Gilgamesh*).**

- **600 BC - the Sybarites (Southern Italy) required noisy tradesmen to ply their trades outside the city walls *(early zoning regulation).***

- **100 AD - the Romans banned wheeled traffic from the Forum because of noise.**

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Historical perspective continued

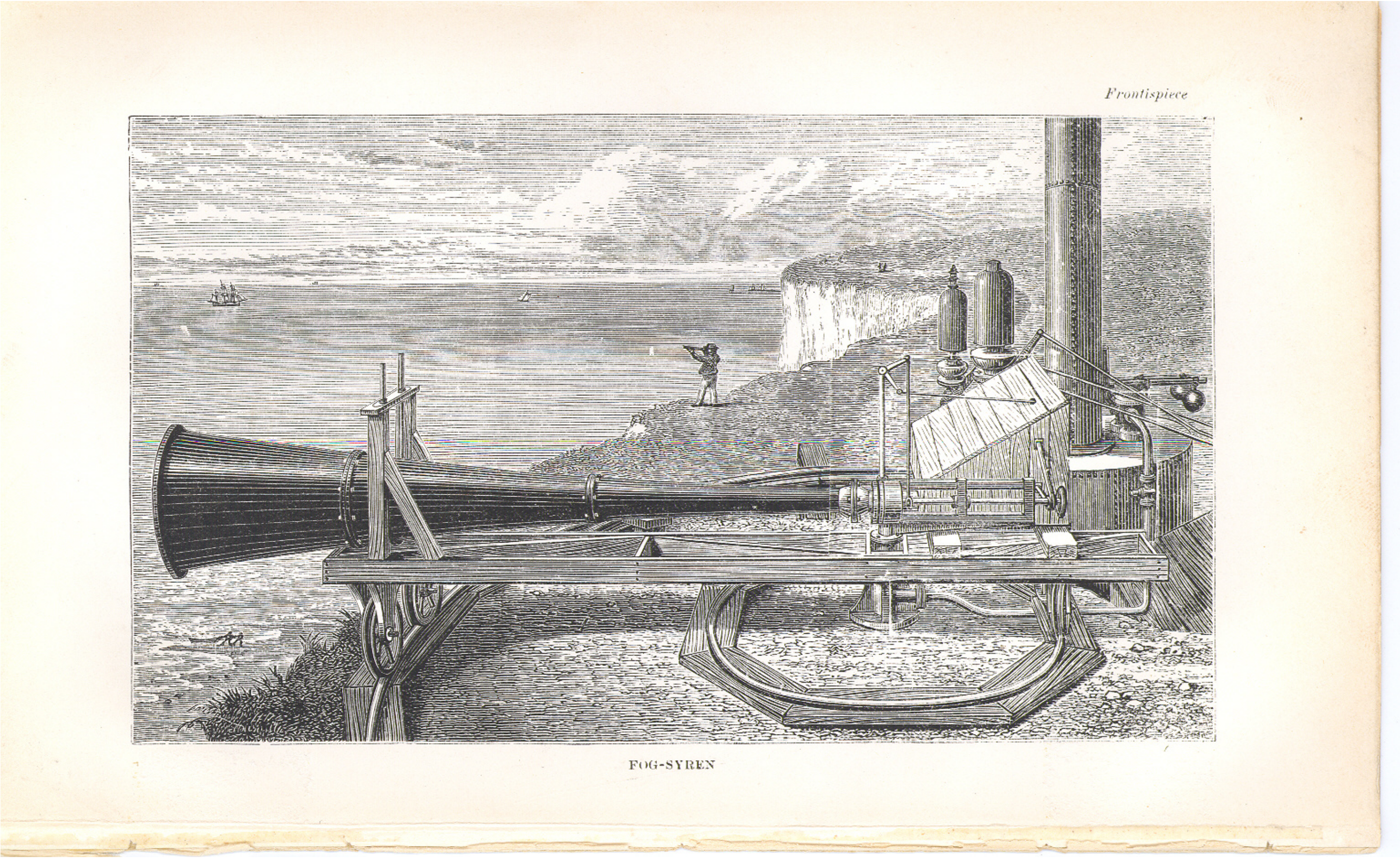
- **1636 - Mersenne measured the speed of sound, obtaining a rather inaccurate value of 448 m/s.**

- **1738 - first precise measurements of the speed of sound; 332 m/s at 0ºC – within 0.3% of the best modern value! (*Academy of Paris)***

- **1850 – Boston is first city in NA to have a noise bylaw.**

Historical perspective continued

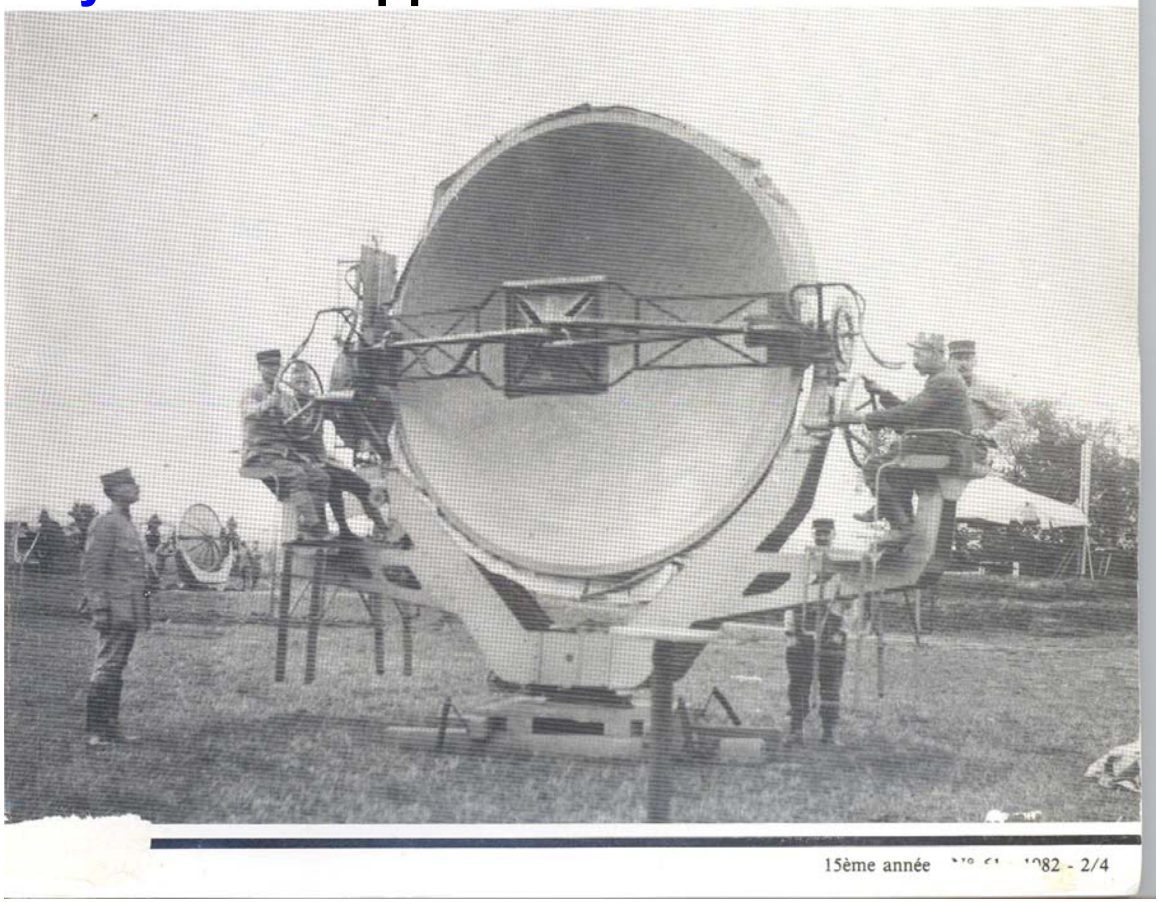
mid-1800's onwards – research on main propagation features



Tyndall (1875) investigating scattering by fog

Historical perspective continued

Early 1900's – applications of outdoor acoustics…



Acoustic detection of planes (war 1914-18)

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Historical perspective – modern work

- 1959 – jet aircraft enter commercial service...
- 1960's onwards - concern over noise resulted in increased scientific activity.
- Progress with both experiments and theory, as well as Standards.
- 1990's - theory includes sophisticated numerical models and engineering models are available for general use

Governing equation

- **When sound propagates, it is attenuated.**
- **This attenuation can be expressed as the sum of three independent terms:**

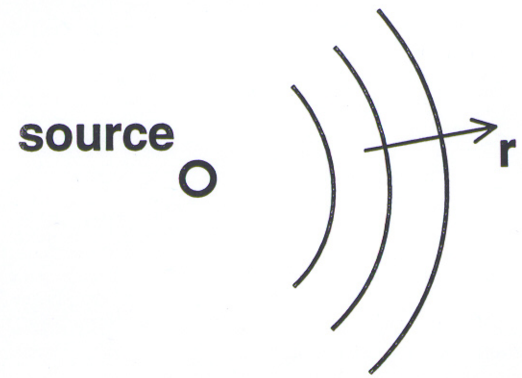
$$\textbf{Total attenuation} = A_{div} + A_{abs} + A_{env}$$

A_{div} geometrical spreading

A_{abs} atmospheric absorption

A_{env} all other attenuation

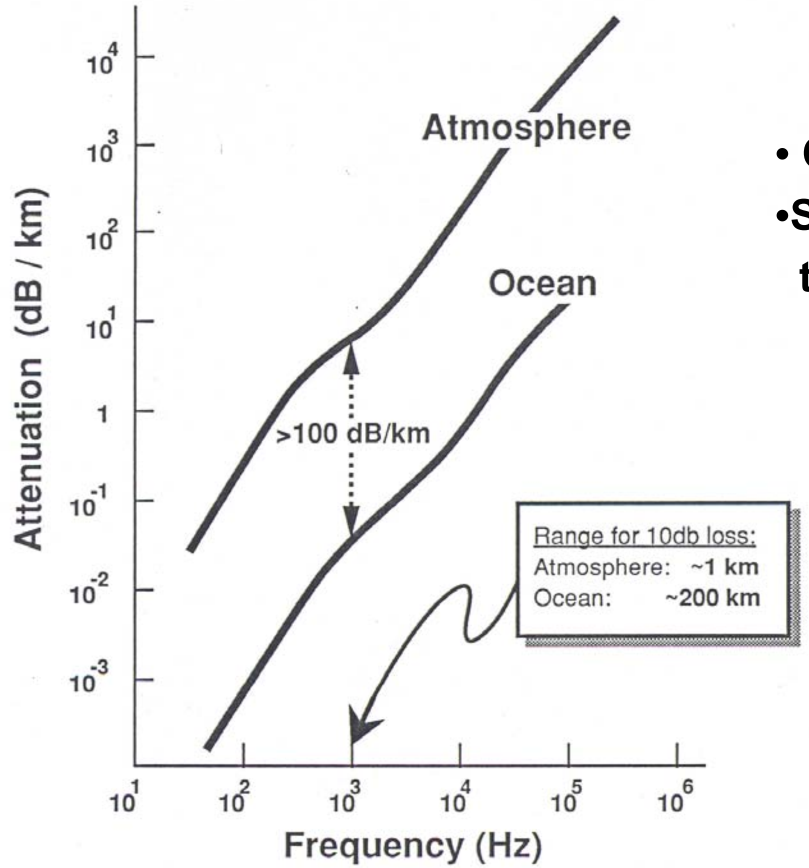
Geometrical spreading, A_{div}



Pressure ∝ 1/r

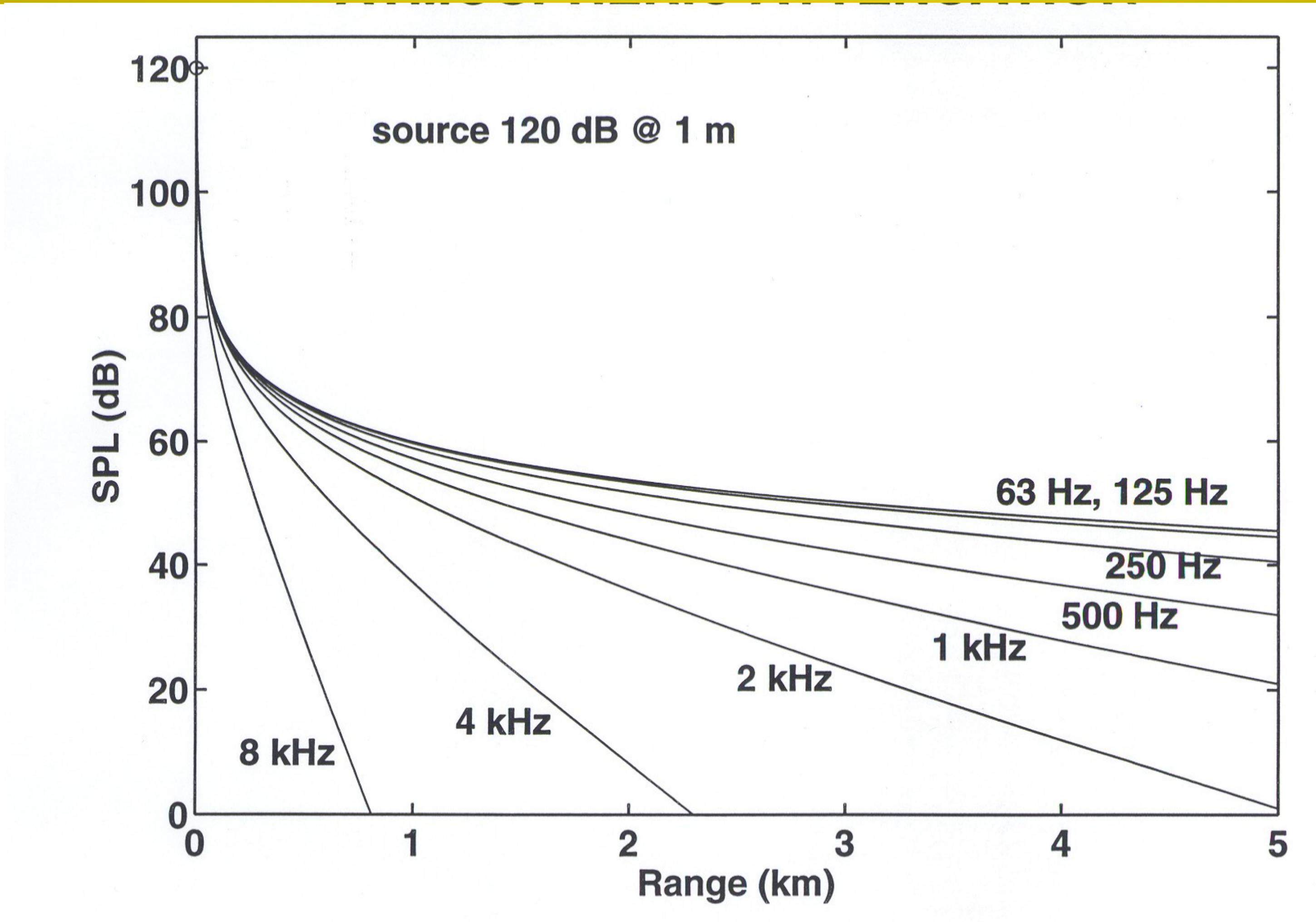
This implies 6 dB decrease per doubling of distance

Atmospheric absorption, A_{abs}

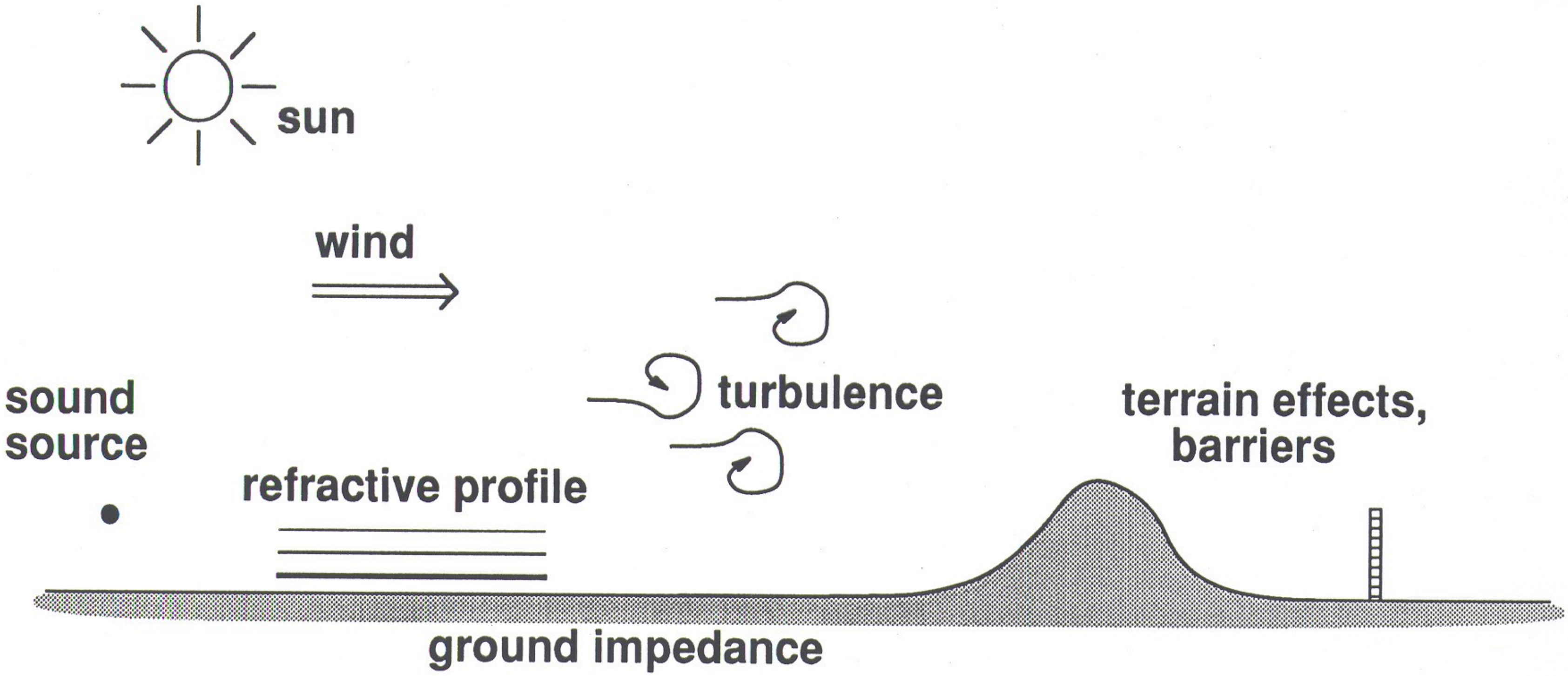


- Calculated using ISO 9613-1
- Strongly dependent on temperature and humidity

The two main attenuation terms, $A_{div} + A_{abs}$



Attenuation by all other effects, A_{env}



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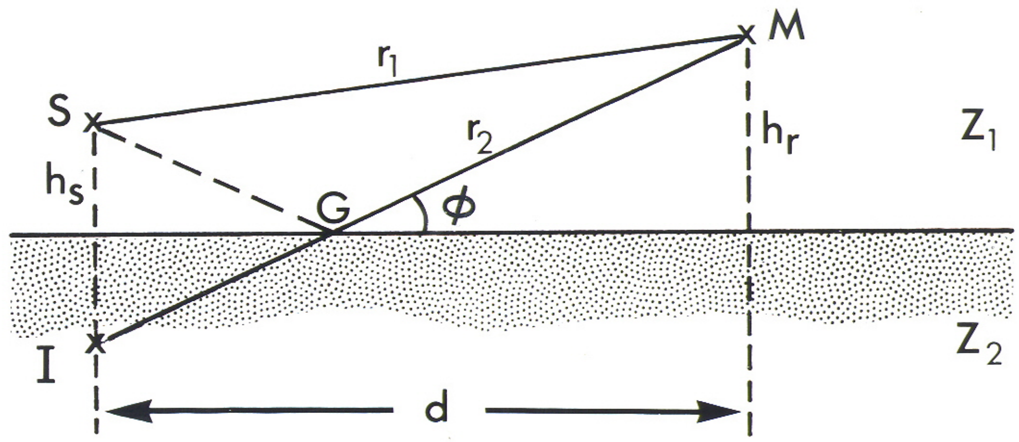
A_{env} in a very calm atmosphere

Point source S above ground



- A_{env} dominated by ground impedance Z_2
- Grazing angle Φ is a critical parameter

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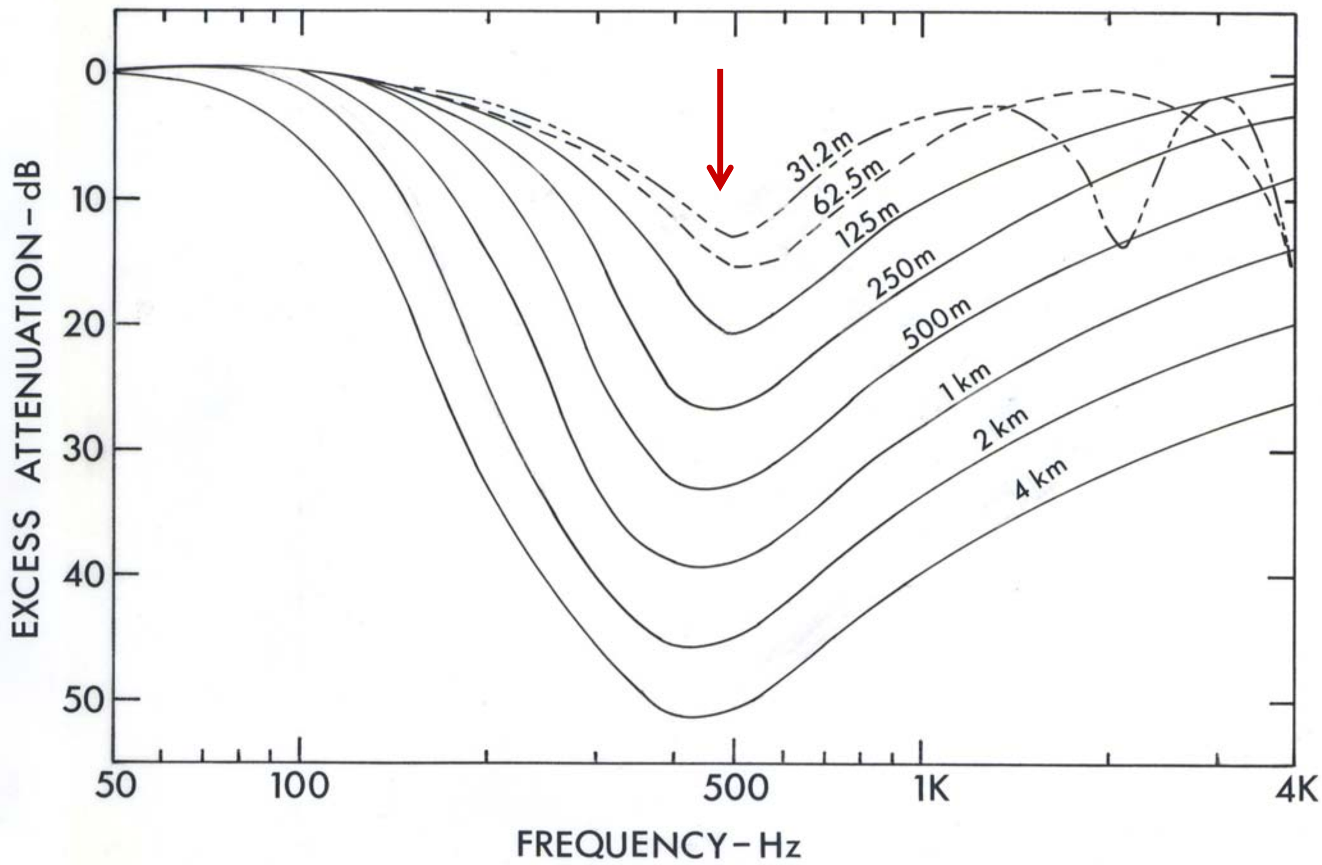
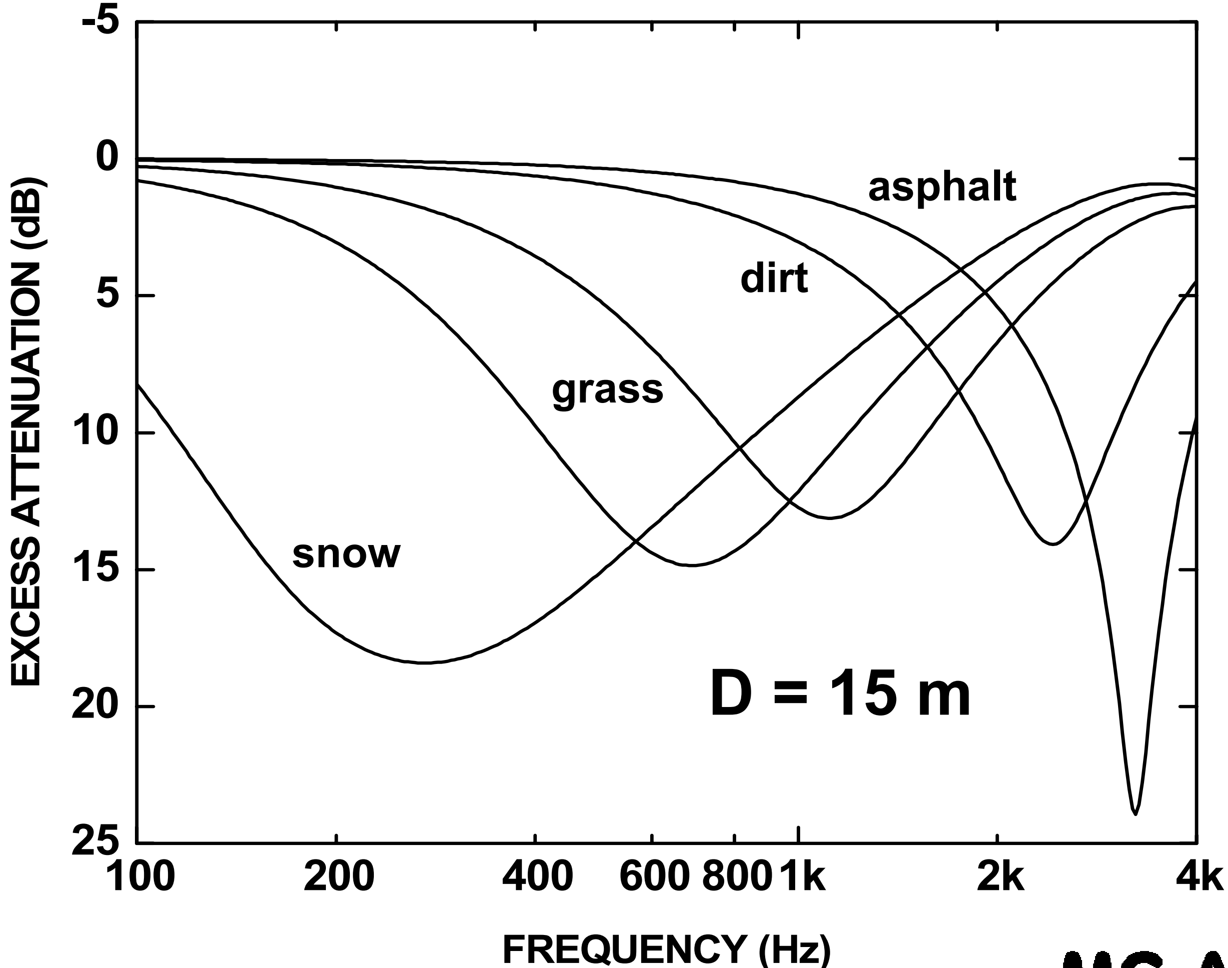
A_{env} in very calm atmosphere continued

Grass-covered ground



A_{env} at short ranges

Different types of ground cover



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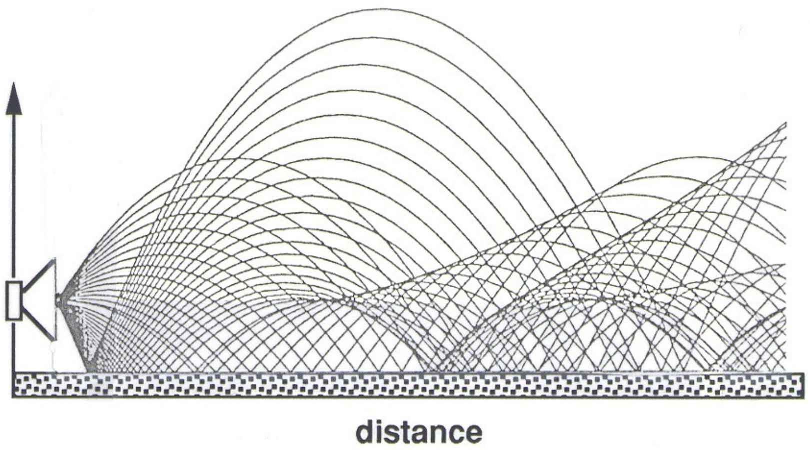
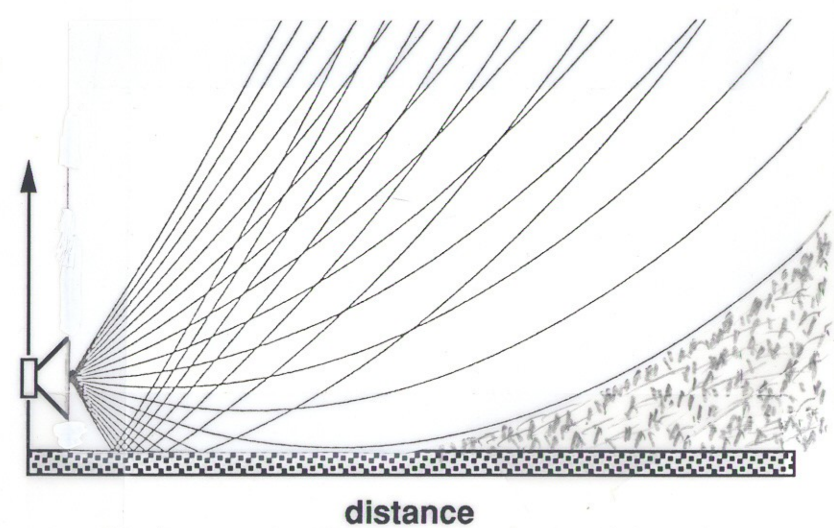
A_{env} at longer ranges

Sound rays in the atmosphere



downwind or nighttime

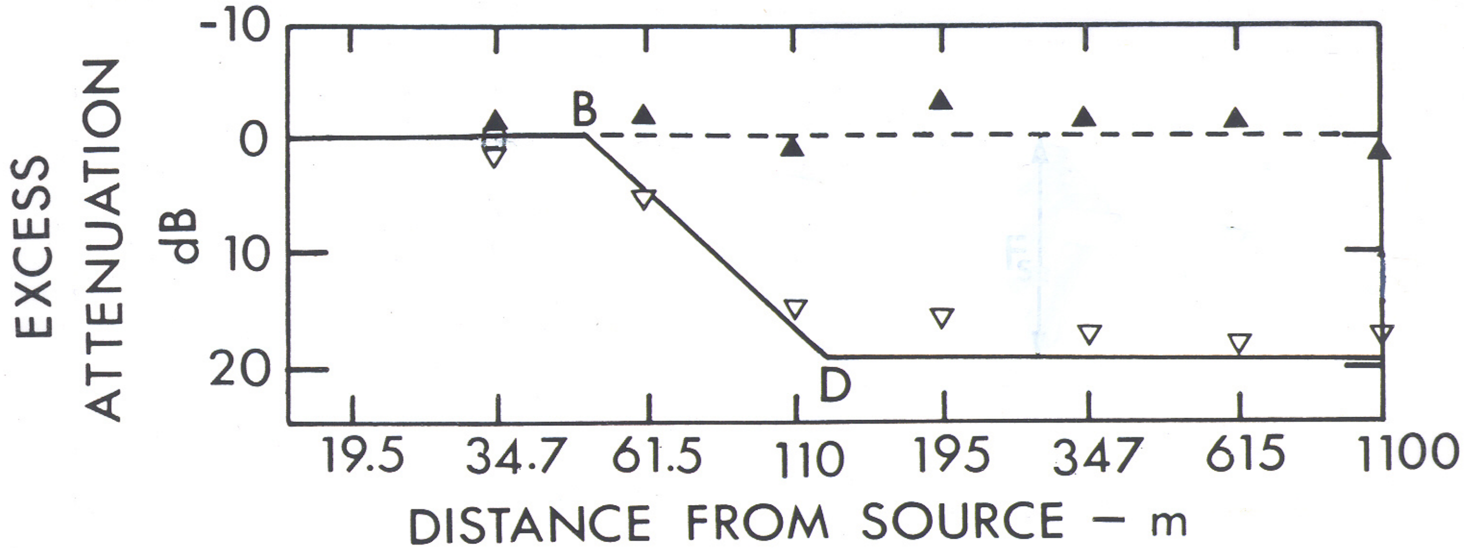
upwind or daytime



A_{env} no longer dominated by ground impedance.

A_{env} at longer ranges - Parkin and Scholes, 1965

Grass-covered airfield **Frequency = 1.2 kHz**



▲ Downwind **▽ Upwind**

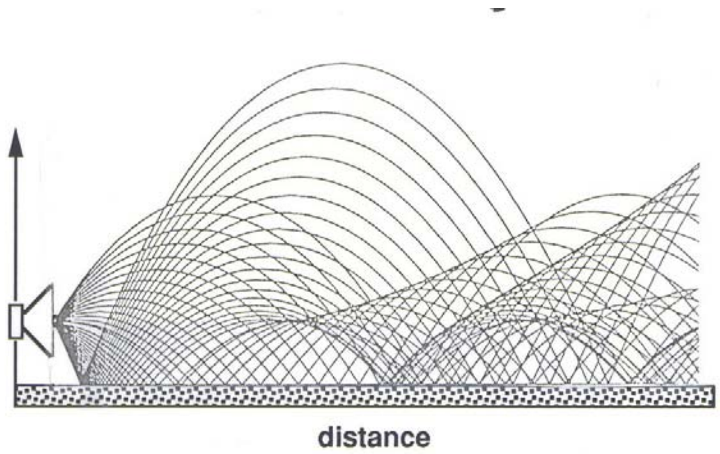
A_{env} at longer distances continued

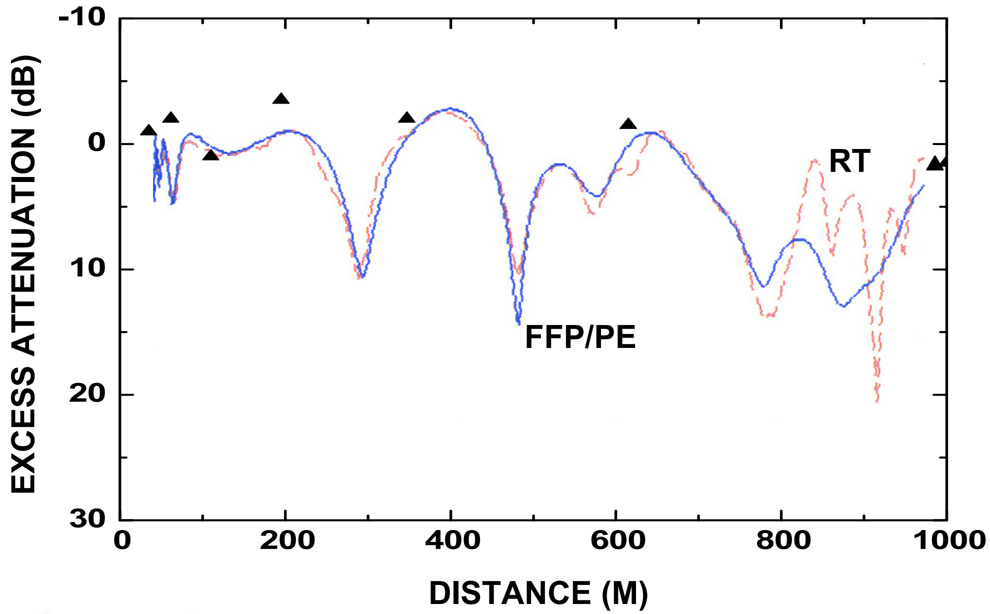
- **A_{env} no longer dominated by ground impedance.**
- **Theory must include atmospheric effects.**

- **Powerful numerical codes:**
  – Advance Ray Tracing techniques (RT)
  – Fast Field Program (FFP)
  – Parabolic equation (PE)

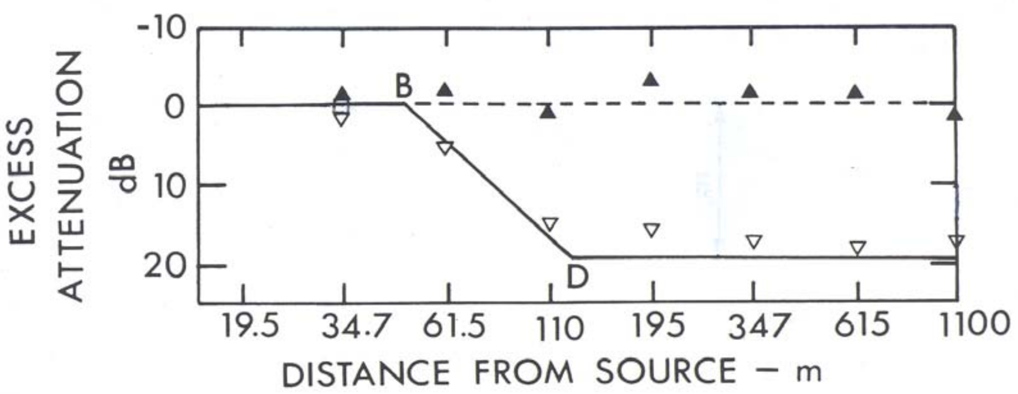
- **Engineering models:**
  – ISO 9613-2
  – Nord2000
  – Harmonoise model

Downward refraction





Parkin & Scholes



▲ Frequency = 1.2 kHz

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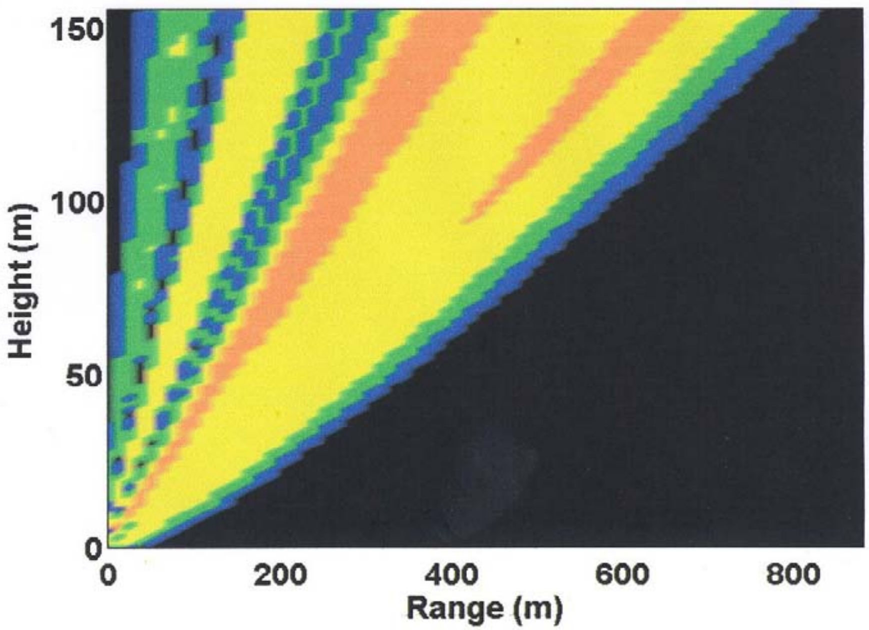
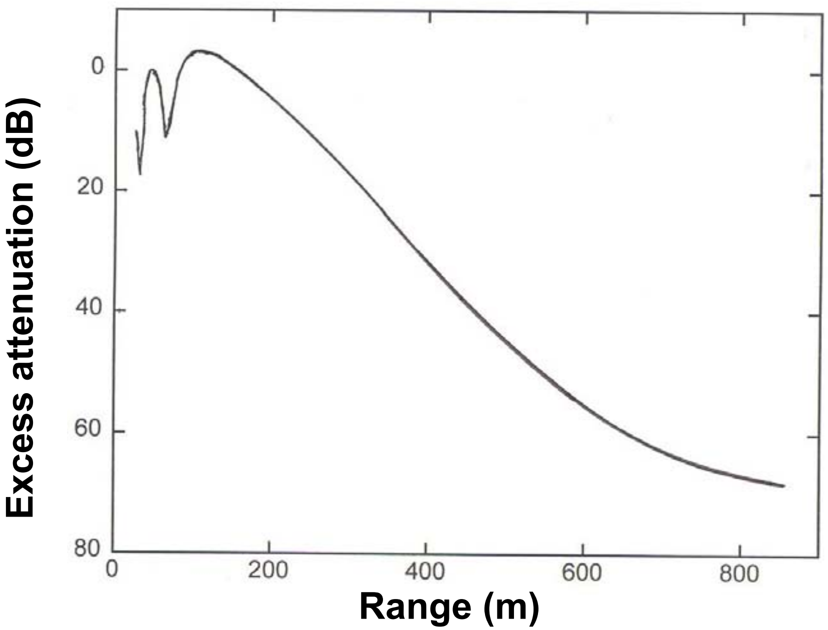
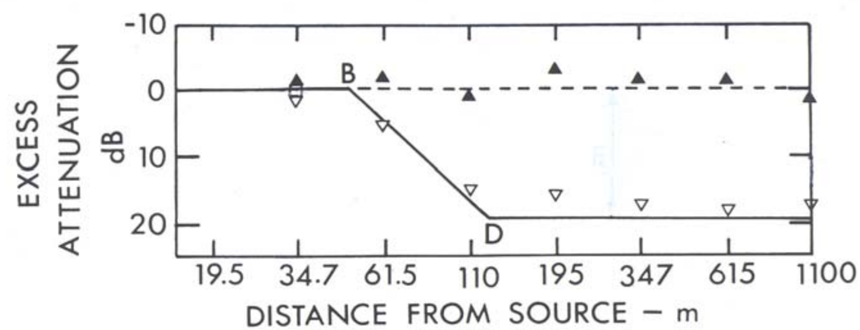
Upward refraction

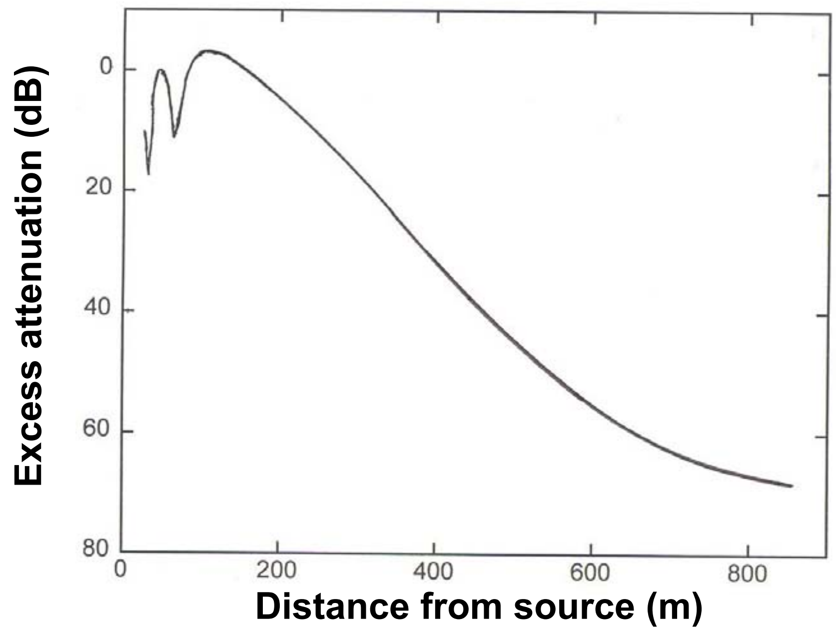




Frequency = 1.2 kHz

Upward refraction continued

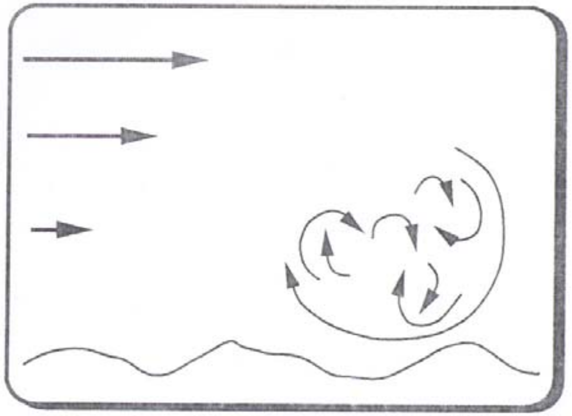




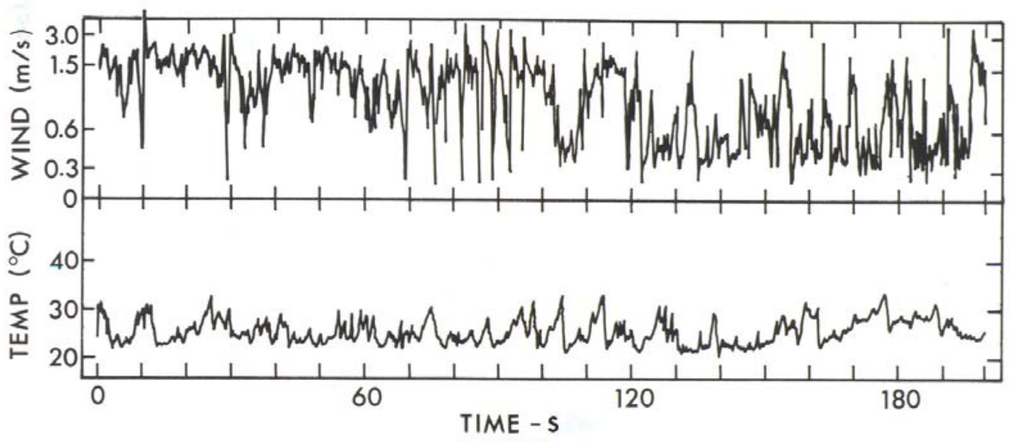
Parkin & Scholes

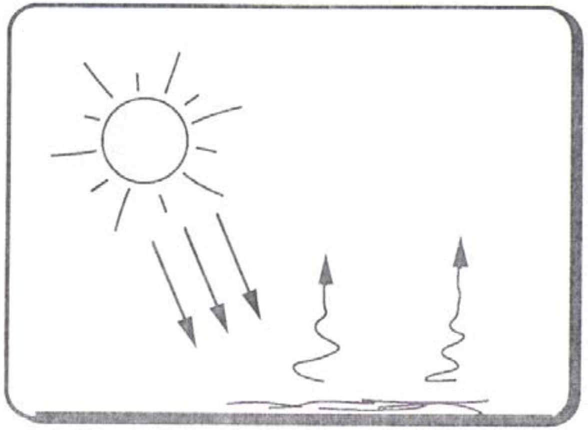
▽ **Frequency = 1.2 kHz**

Turbulence



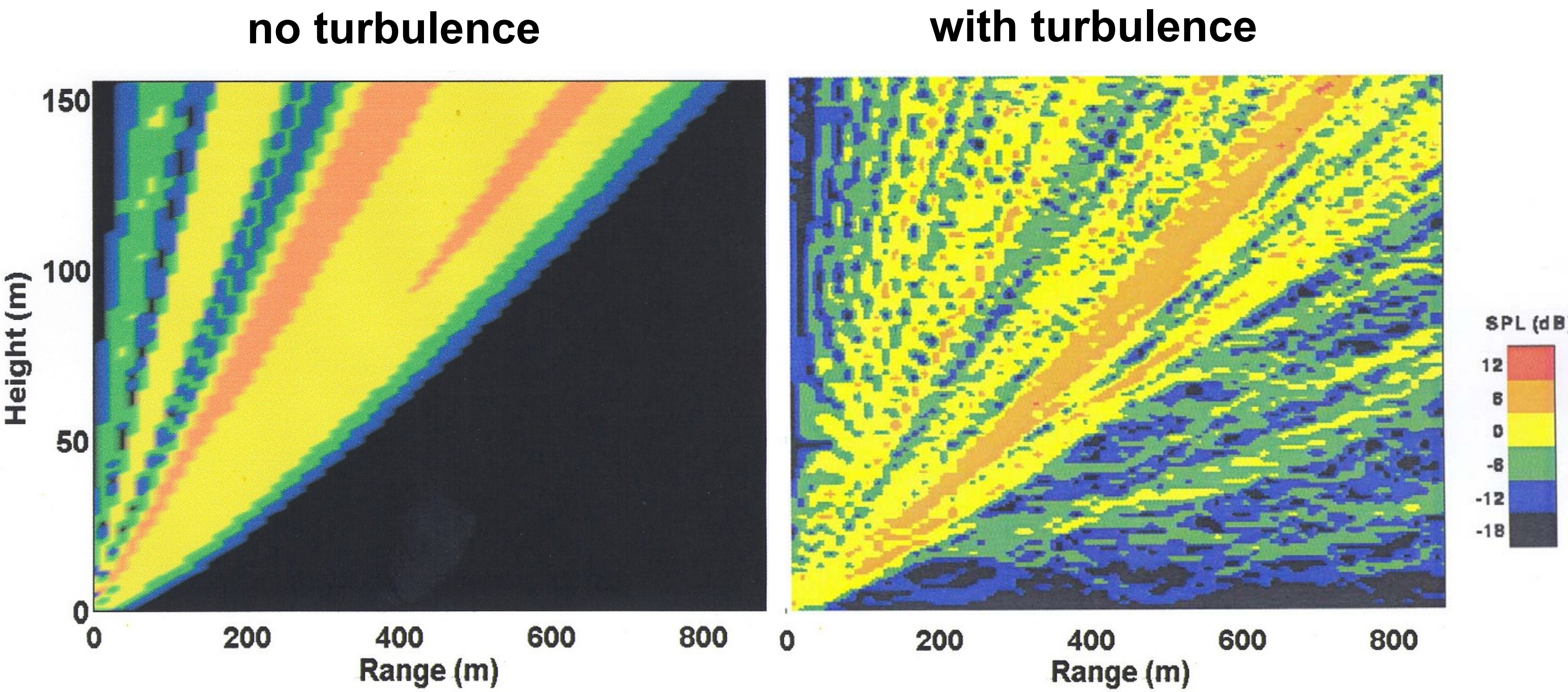
Wind shear





Thermal mixing

Upward refraction with turbulence



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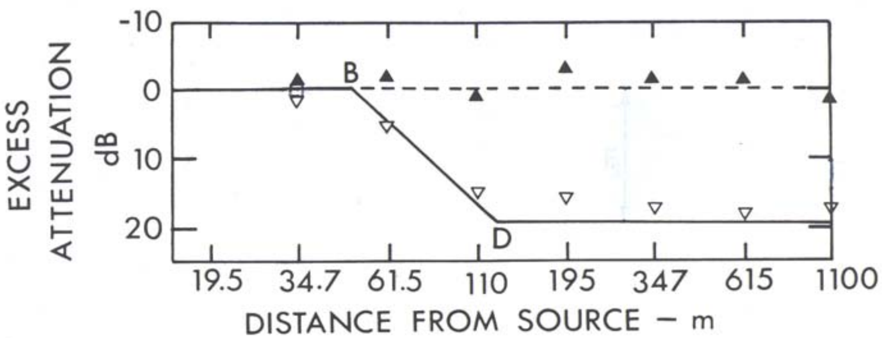
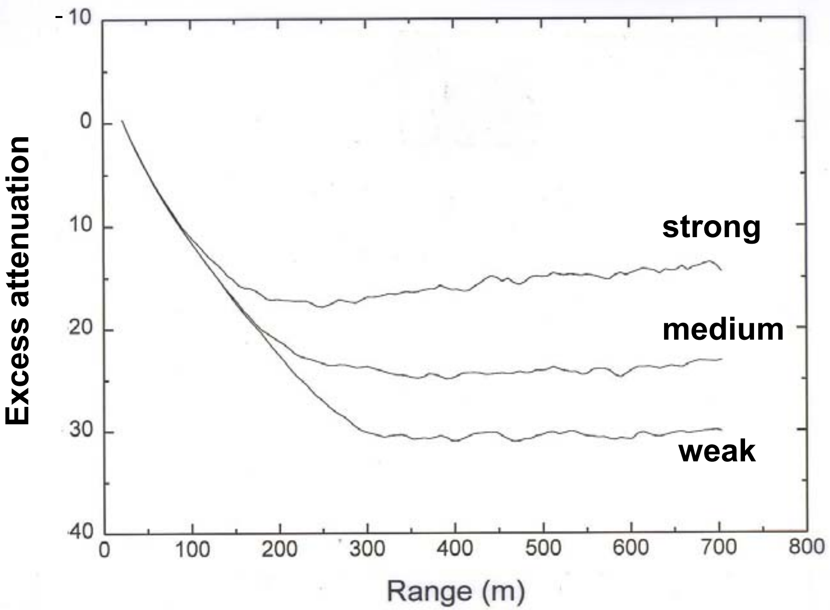
Upward refraction with turbulence continued





Parkin & Scholes

▽ **Frequency = 1.2 kHz**

PE calculations

strong, medium weak turbulence

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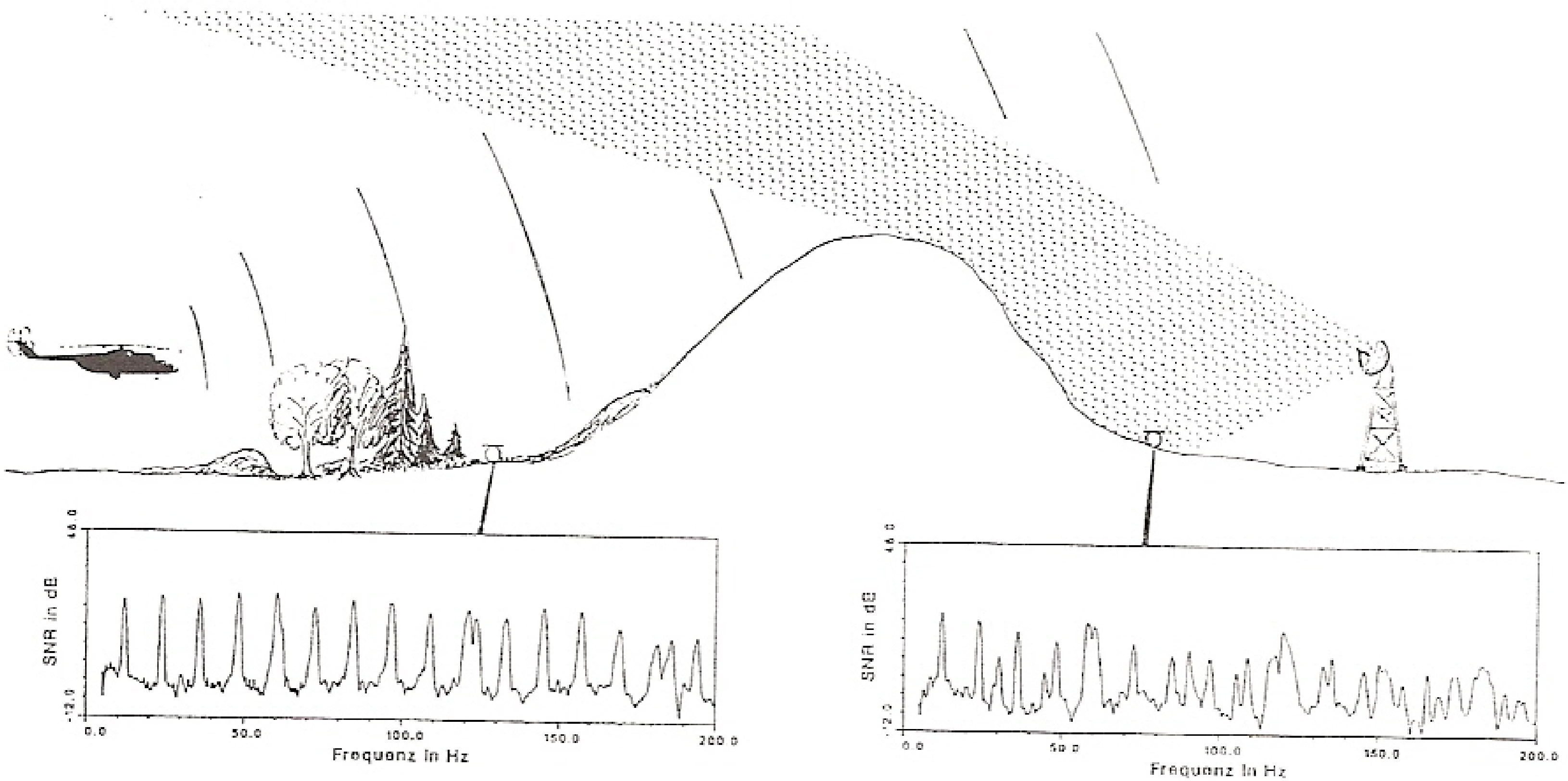
Practical application of Numerical Models

Detection, identification and localisation of sources



Line of sight signature

Diffracted signature

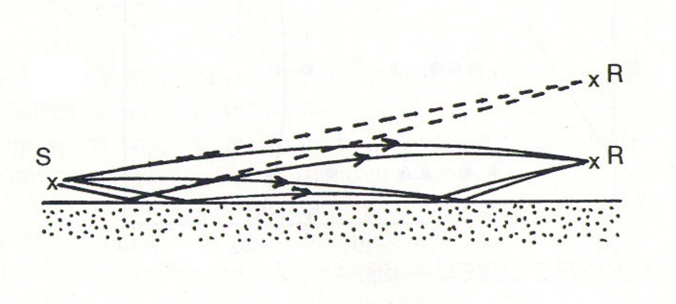
Engineering models

- ISO 9613-2
- Nord2000
- Harmonoise model

A_{env} from ISO 9613-2

- **Prediction applies to meteorological conditions favorable to propagation:**
  - Downwind propagation
  - Temperature inversion (nighttime)

- **Produces levels that are rarely exceeded**



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A_{env} from ISO 9613-2 continued

- In the case where the sound speed profile varies linearly with height, there is a closed form solution for all the sound rays.

- There are families of rays that reflect from the ground:
  - in the middle region
  - close to the source
  - close to the receive

Source region

Middle region

Receiver region

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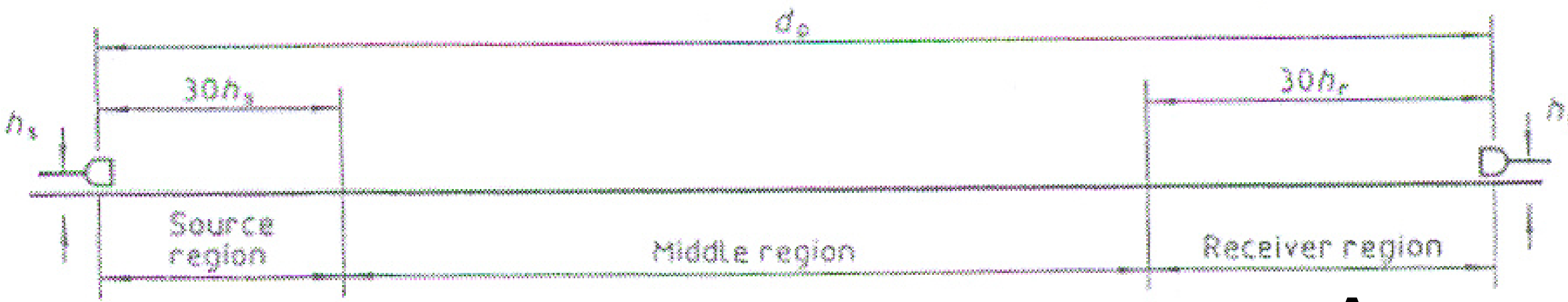
A_{env} from ISO 9613-2 continued

$$A_{env} = A_s + A_r + A_m$$

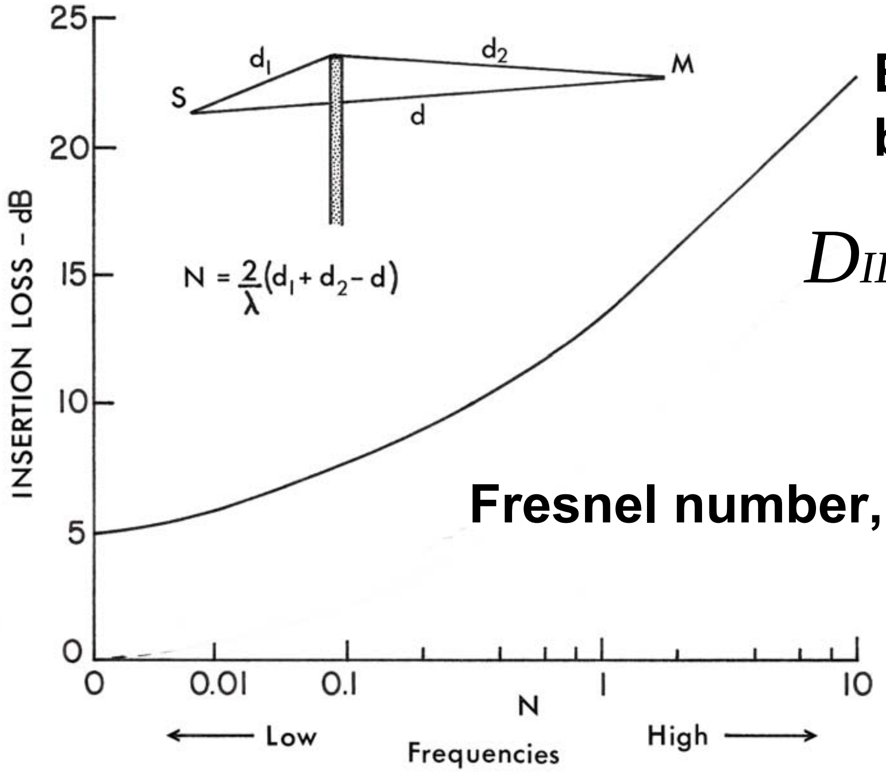


A_s A_m A_r

Source region Middle region Receiver region

Soft (G = 1) or hard ground (G = 0)

Insertion loss of barrier from and Fresnel number



Barrier performance is measured by its **Insertion loss**, D_{IL}

$$D_{IL} = L_p(before) - L_p(after)$$

Fresnel number, *N*

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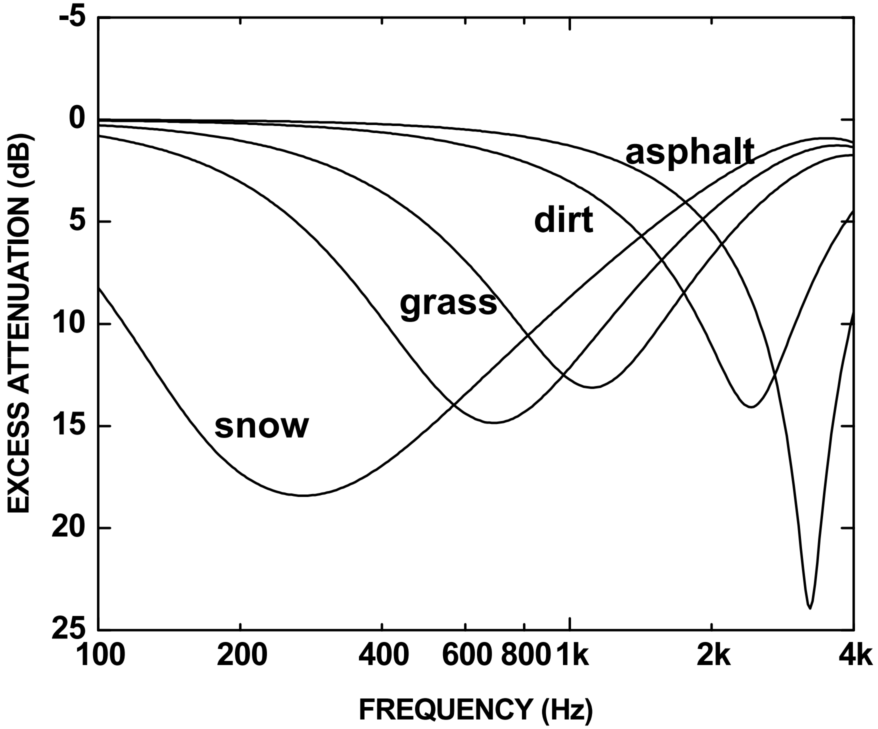
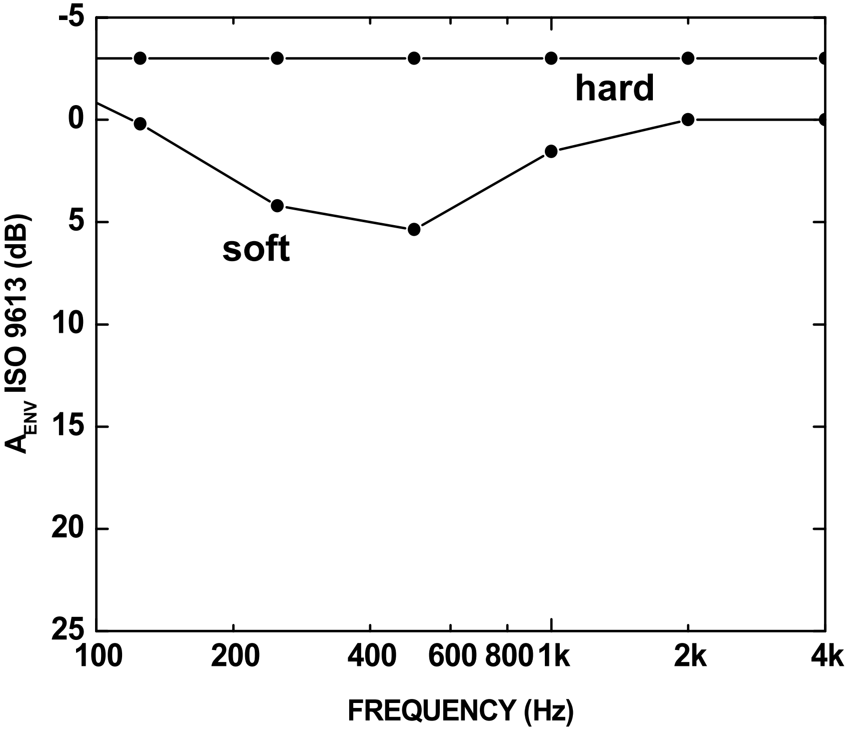
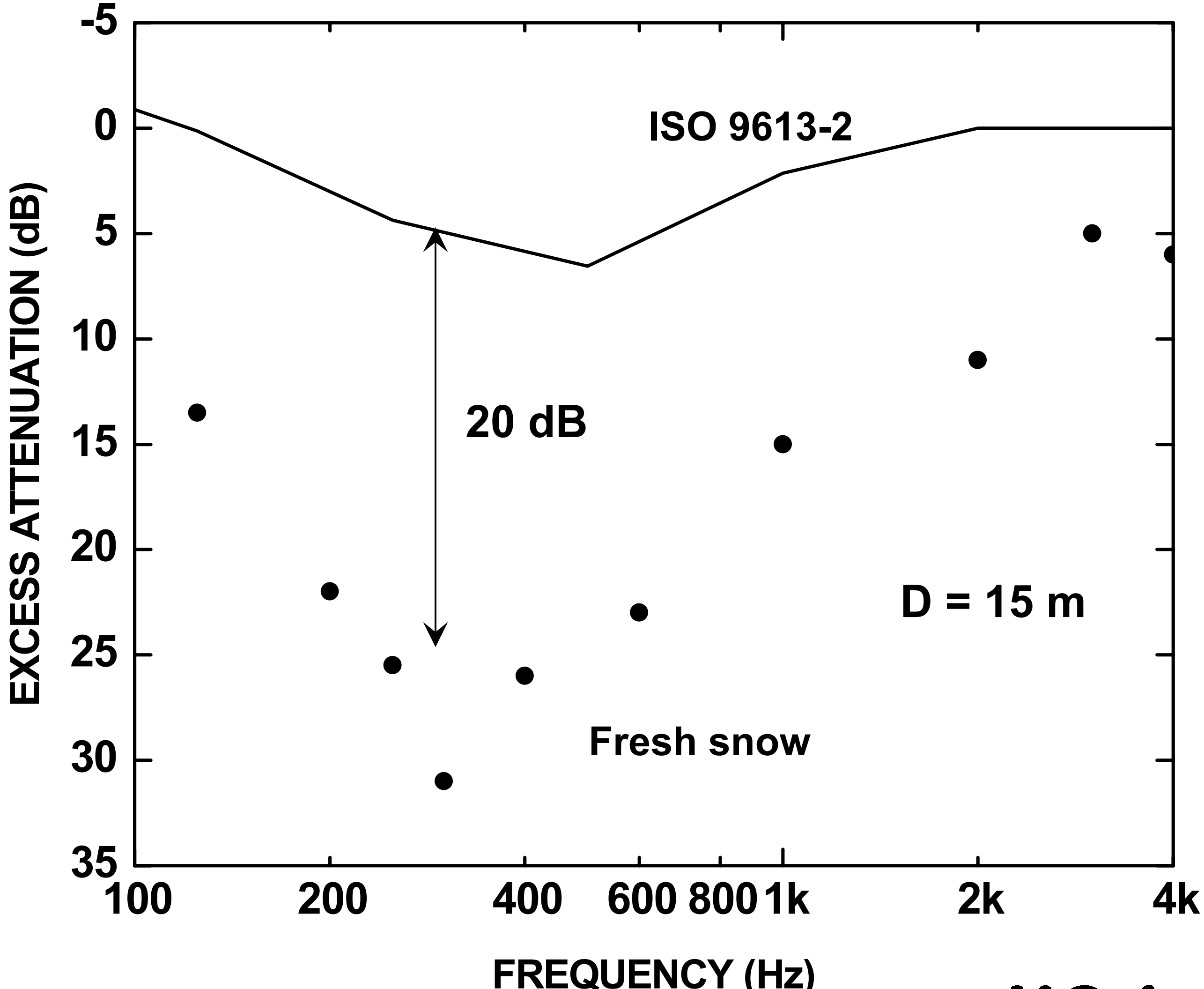
A_{env} from ISO 9613-2, short range





Short range, D = 15 m

A_{env} from ISO 9613-2, short range continued



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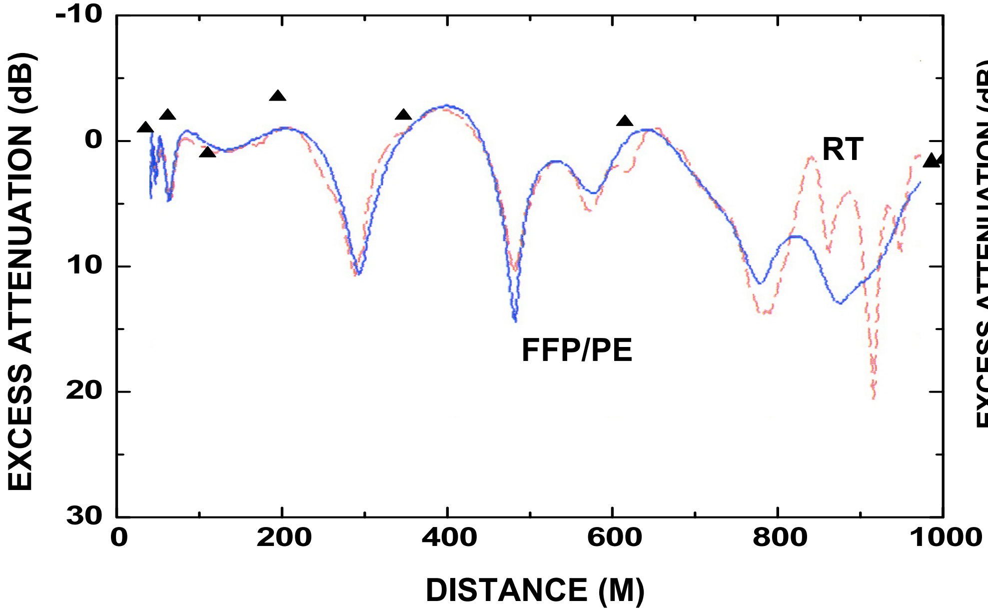
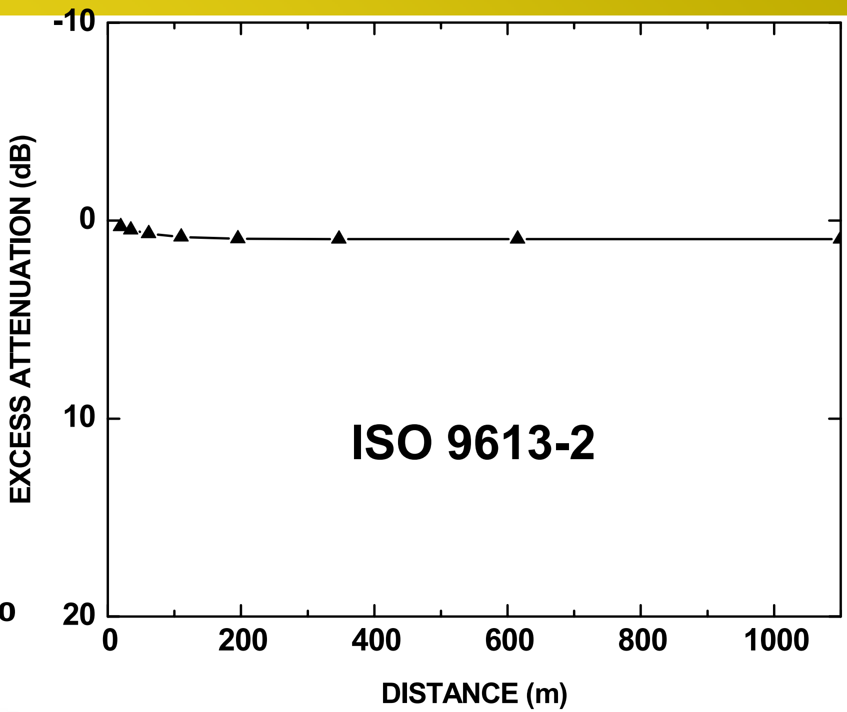
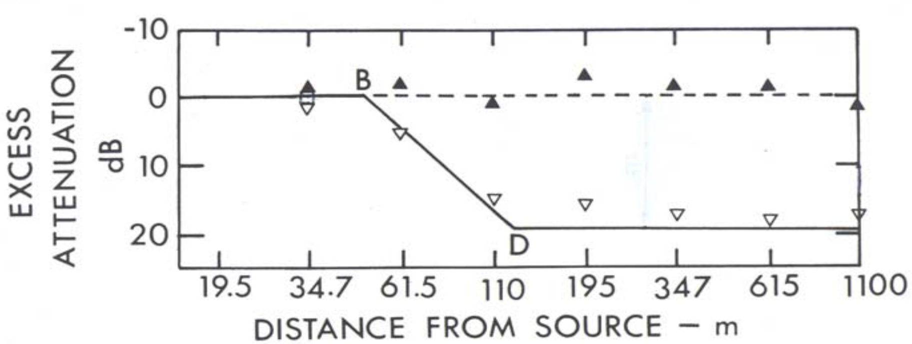
A_{env} from ISO 9613-2, longer ranges







Parkin & Scholes

▲ Frequency = 1.2 kHz

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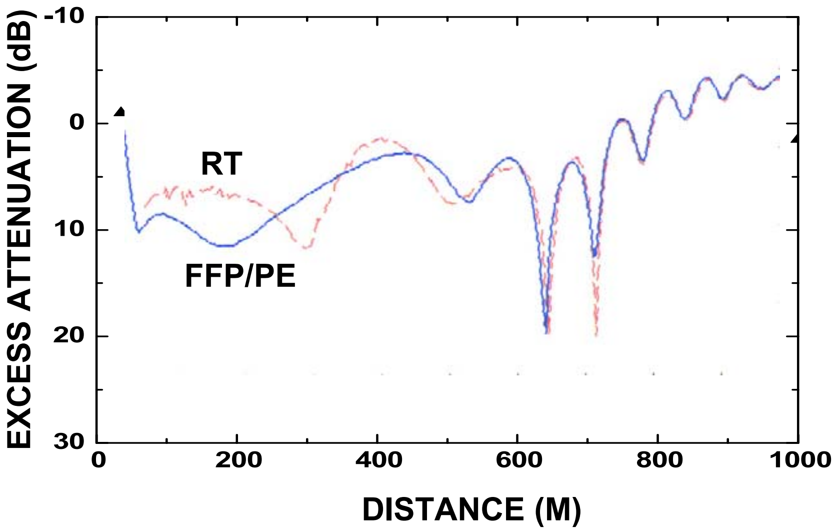
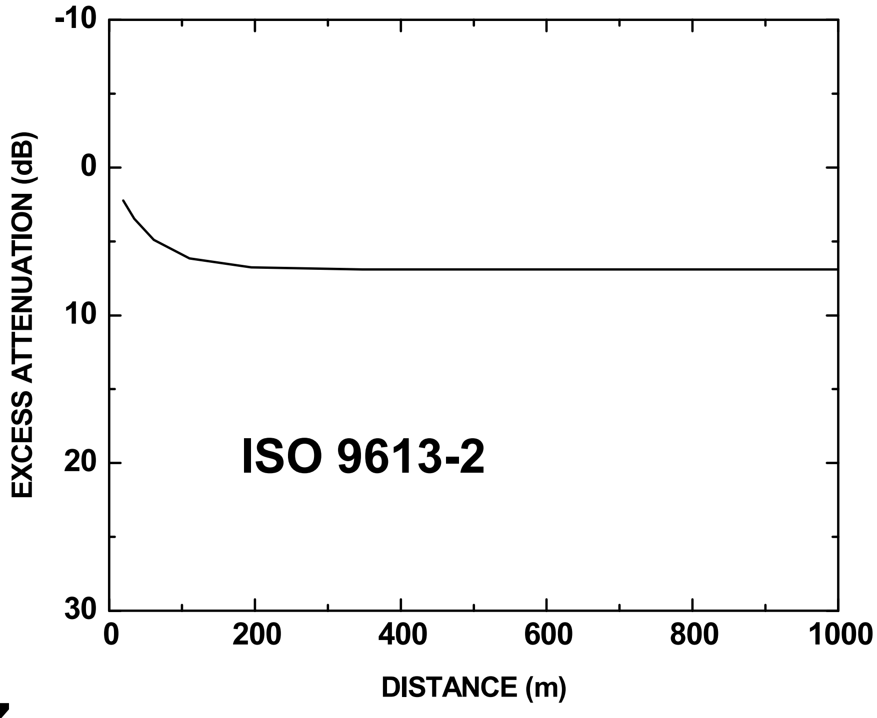
A_{env} from ISO 9613-2, longer ranges continued





Frequency = 250 Hz

Grass covered ground

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A_{env} from the Nord2000 model

- **Accounts for:**
  - different impedance grounds
  - terrain effects
  - refraction
  - turbulence
- **More detailed barrier calculation**

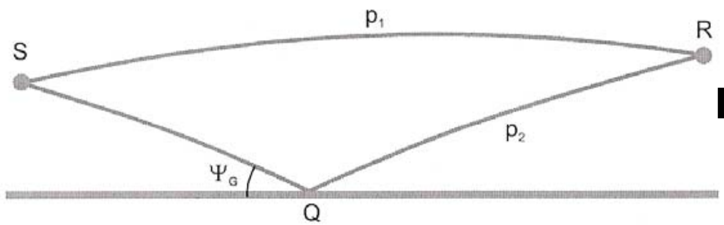
A_{env} from the Nord2000 model

Accounts for different types of grounds

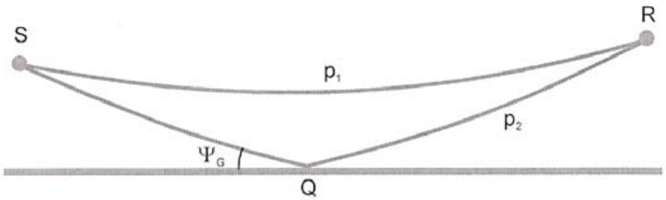
Impedance class	Representative flow resistivity σ (kNsm^{-4})	Range of Nord-test flow resistivity classes	Description
A	12.5	10, 16	Very soft (snow or moss-like)
B	31.5	25, 40	Soft forest floor (short, dense heather-like or thick moss)
C	80	63, 100	Uncompacted, loose ground (turf, grass, loose soil)
D	200	160, 250	Normal uncompacted ground (forest floors, pasture field)
E	500	400, 630	Compacted field and gravel (compacted lawns, park area)
F	2000	2000	Compacted dense ground (gravel road, parking lot, ISO 10844)
G	20000	-	Hard surfaces (most normal asphalt, concrete)
H	200000	-	Very hard and dense surfaces (dense asphalt, concrete, water)

A_{env} from the Nord2000 model

Accounts for curved rays and modified grazing angle *Ψ* at the ground



Downward refraction



Upward refraction

A_{env} from the Nord2000 model

General form of the sound speed profile

$$c(z) = c_0 + B\ln\left(\frac{z}{z_0} + 1\right) + Az$$

Where

$$A = f(u_*, T_*, L)$$

and also

$$B = f(u_*, T_*, L)$$

- u_* **friction velocity**
- T_* **temperature scale**
- L **Monin-Obukhov length**

A_{env} from the Nord2000 model

How to determine *A* and *B*

Table 5.1. Wind speed classification.

wind speed component at 10 m above ground	wind speed class
0 to 1 m/s	W1
1 to 3 m/s	W2
3 to 6 m/s	W3
6 to 10 m/s	W4
> 10 m/s	W5

Table 5.2. Classification of atmospheric stability.

time of day	cloud cover	stability class
day	0/8 to 2/8	S1
day	3/8 to 5/8	S2
day	6/8 to 8/8	S3
night	5/8 to 8/8	S4
night	0/8 to 4/8	S5

Table 5.3. Friction velocity, by wind speed class

wind speed class	u_* in m/s
W1	0.00
W2	0.13
W3	0.30
W4	0.53
W5	0.87

Table 5.4. Temperature scale T_*, by wind speed class and stability class

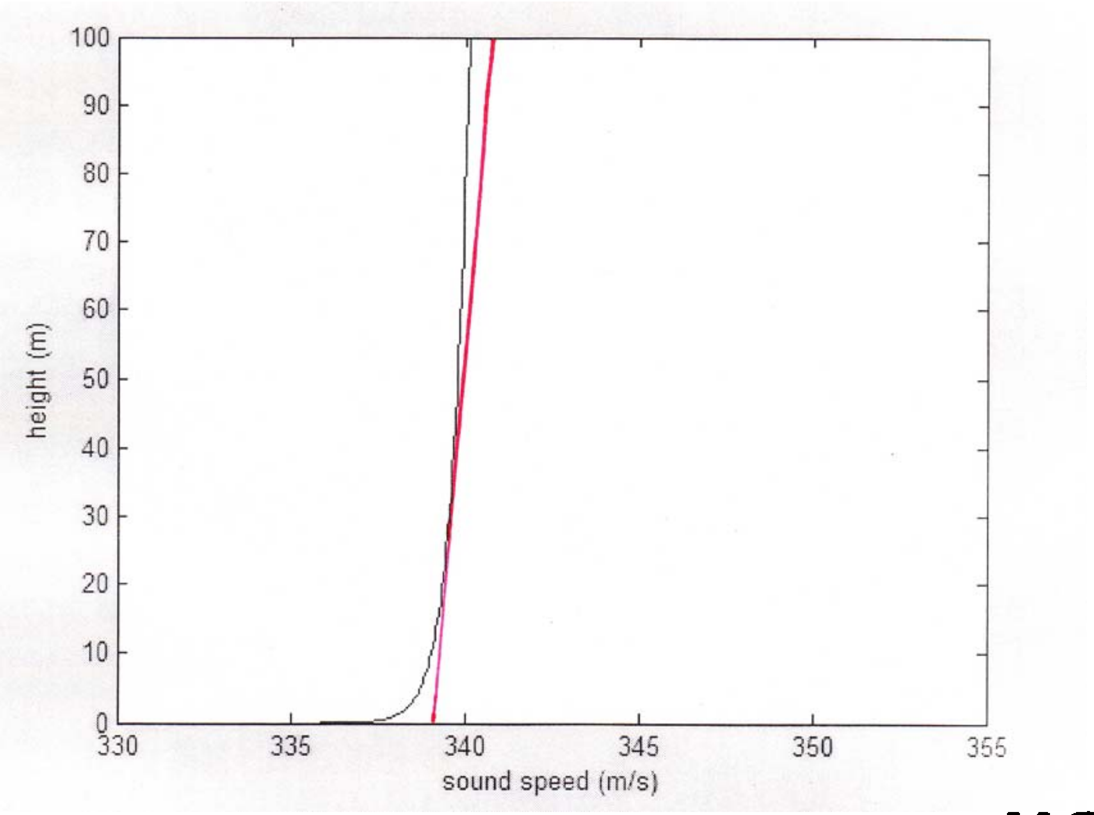
	S1	S2	S3	S4	S5
W1	-0.4	-0.2	0.0	+0.2	+0.4
W2	-0.2	-0.1	0.0	+0.1	+0.2
W3	-0.1	-0.05	0.0	+0.05	+0.1
W4	-0.05	0.0	0.0	0.0	+0.05
W5	0.0	0.0	0.0	0.0	0.0

Table 5.5. inverse of the Monin-Obukhov length 1/L, by wind speed class

	S1	S2	S3	S4	S5
W1	-0.08	-0.05	0.0	+0.04	+0.06
W2	-0.05	-0.02	0.0	+0.02	+0.04
W3	-0.02	-0.01	0.0	+0.01	+0.02
W4	-0.01	0.0	0.0	0.0	+0.01
W5	0.0	0.0	0.0	0.0	0.0

A_{env} from the Nord2000 model

- However, the sound speed profile is linearized (red curve) to take advantage of the closed solution for the sound rays.
- Normally, the position of the red curve is frequency dependent.



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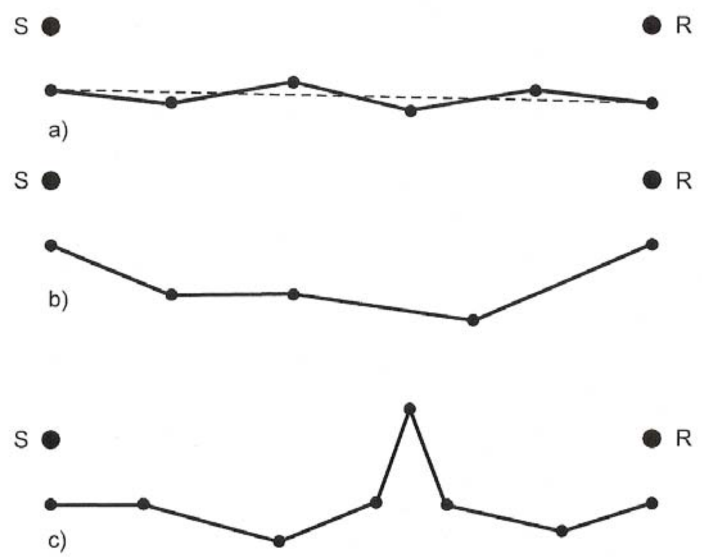
A_{env} from the Nord2000 model

Terrain effects are taken into account by "segmenting" the ground surface



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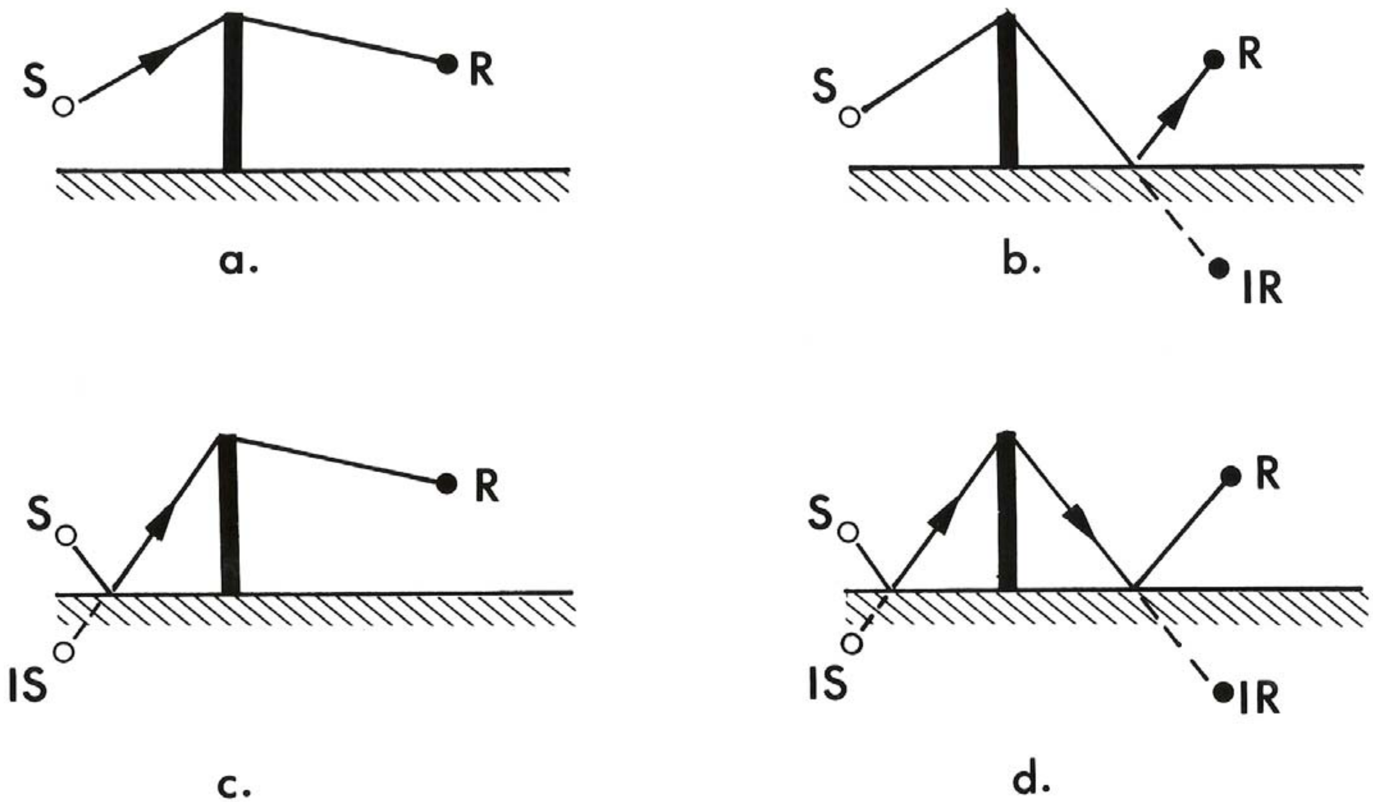
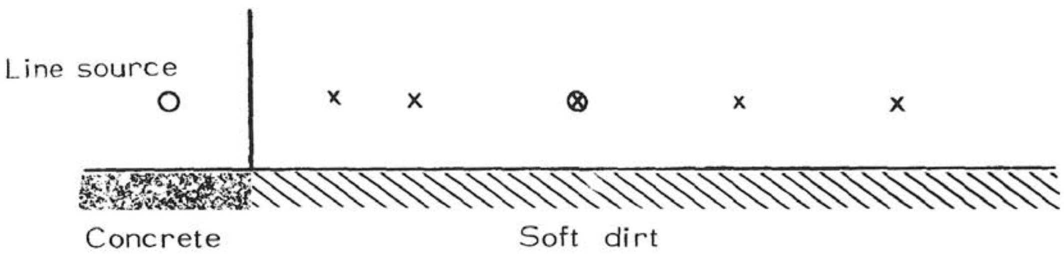
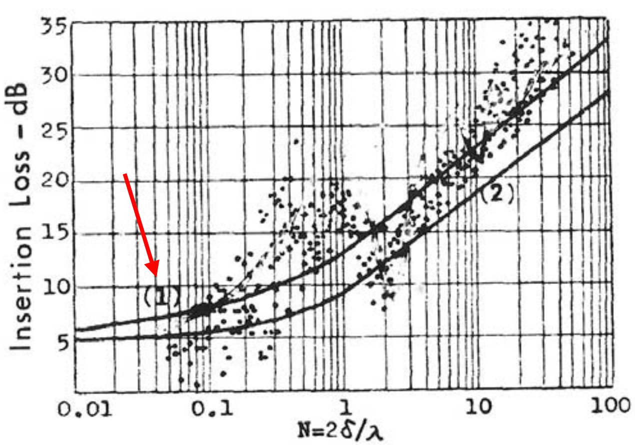
Nord2000 - barriers

four paths can be identified between source and receiver



Effects of the ground "in detail"





- measurements

Curve (1), Maekawa's theory

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Nord2000 - barriers

All curved rays are taken into account as well as modified grazing angles

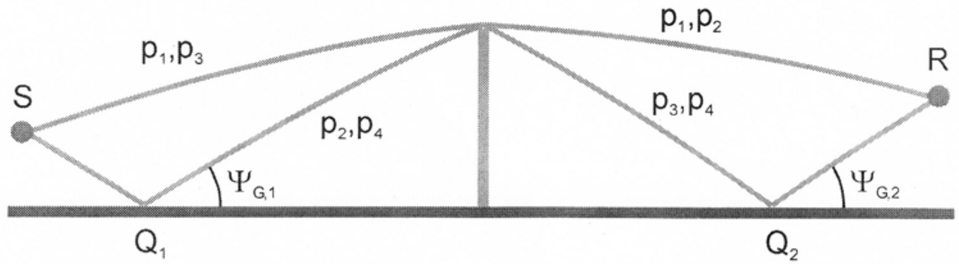
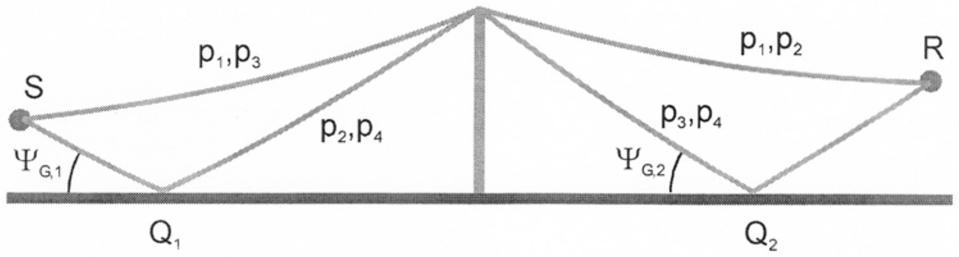
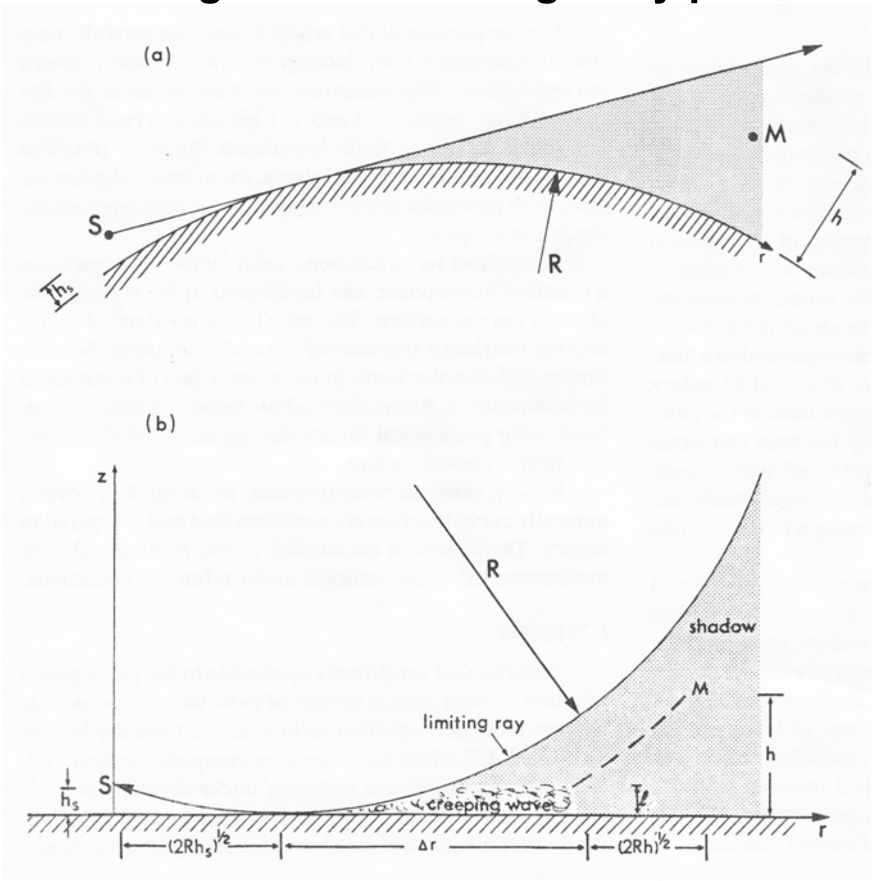


Figure 9
Ray model for a single screen and downward refraction.



Nord2000 versus Harmonoise model

- Harmonoise is based on the same principles as Nord2000.
- However, once the linear sound speed profile is known, Harmonoise assumes a curved ground and straight ray paths for the calculation.



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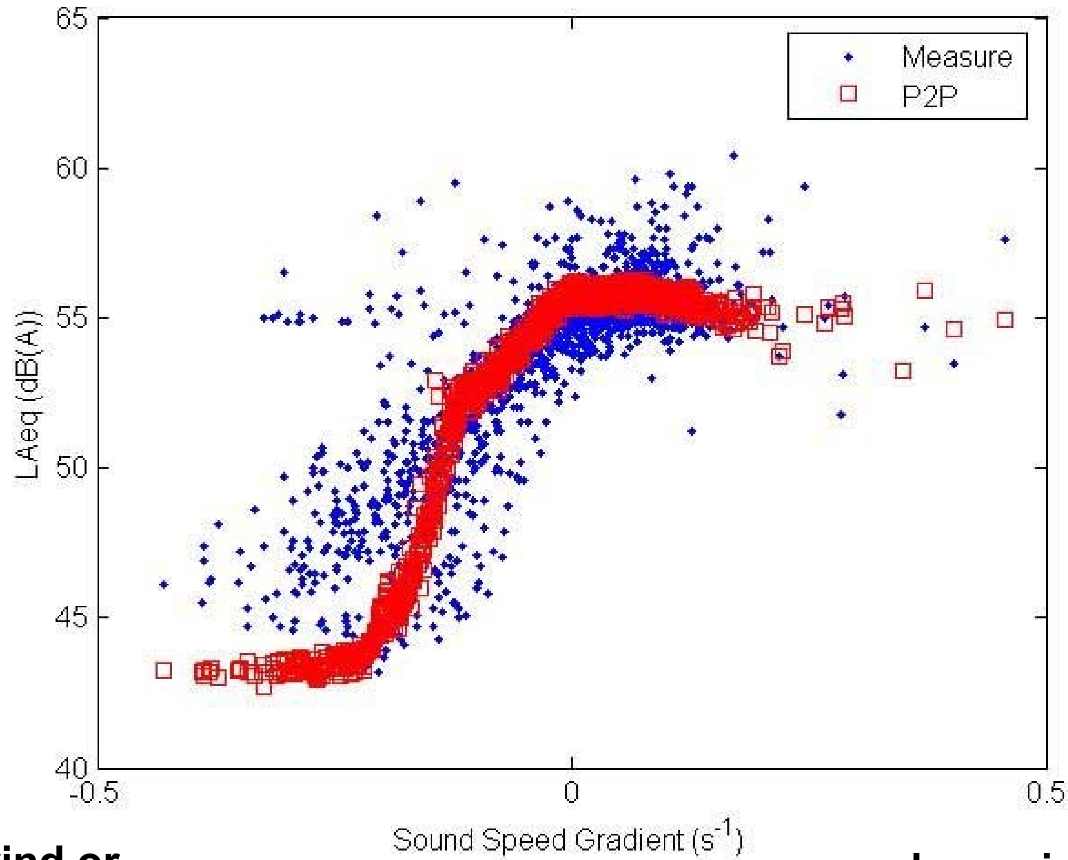
Validation of Harmonoise model



upwind or temperature lapse

downwind or inversion

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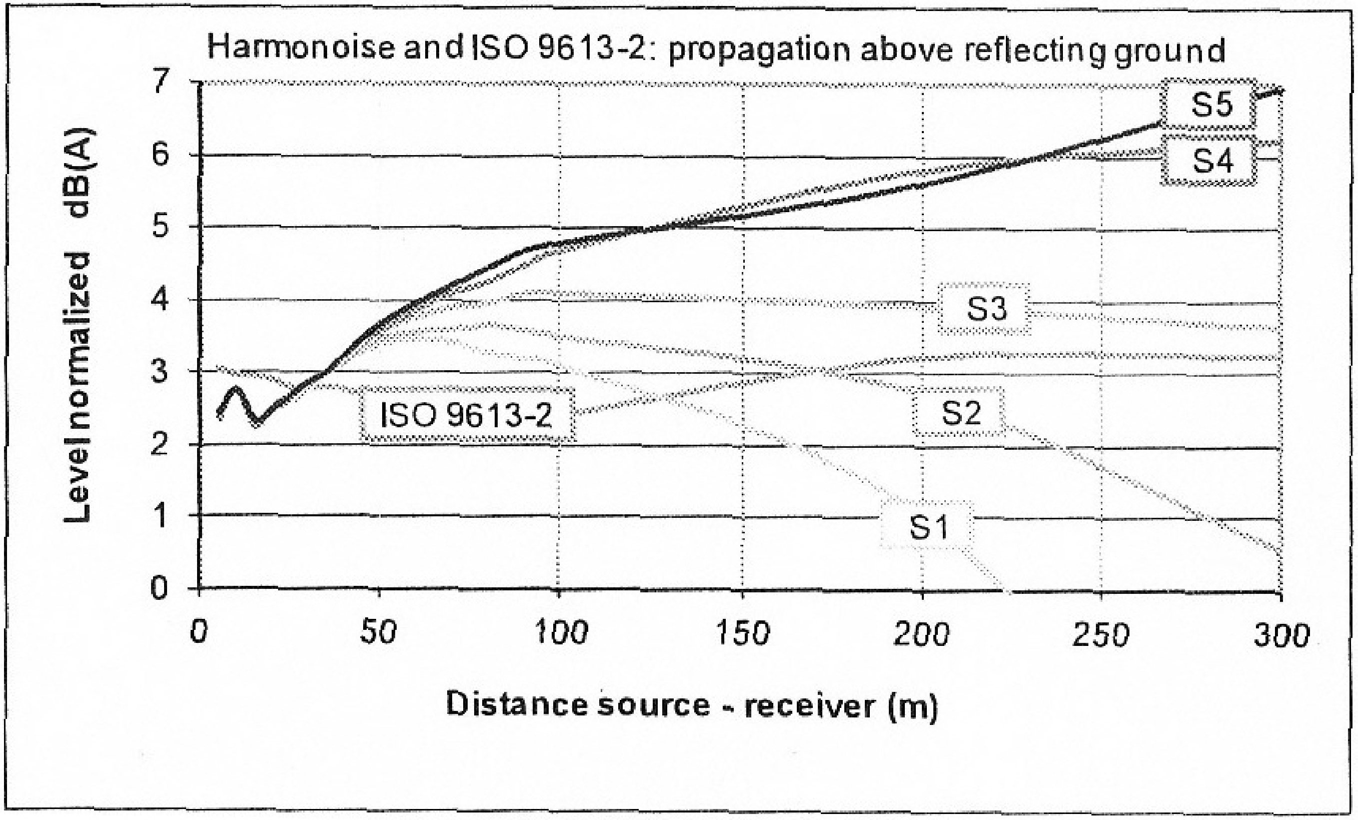
ISO 9613-2 versus Harmonoise



from W. Probst, INTER-NOISE 2013

… the end

thank you…