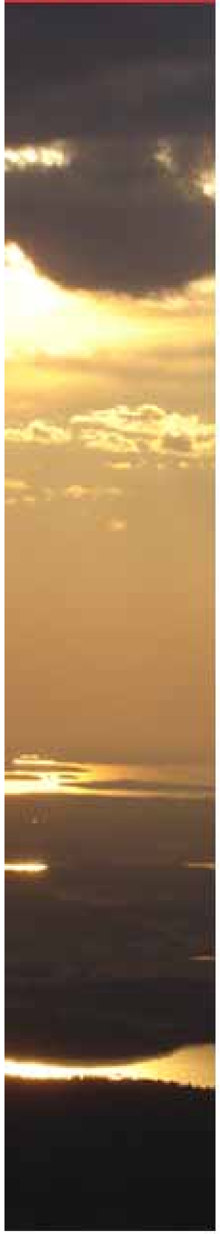

Sound propagation from wind turbines

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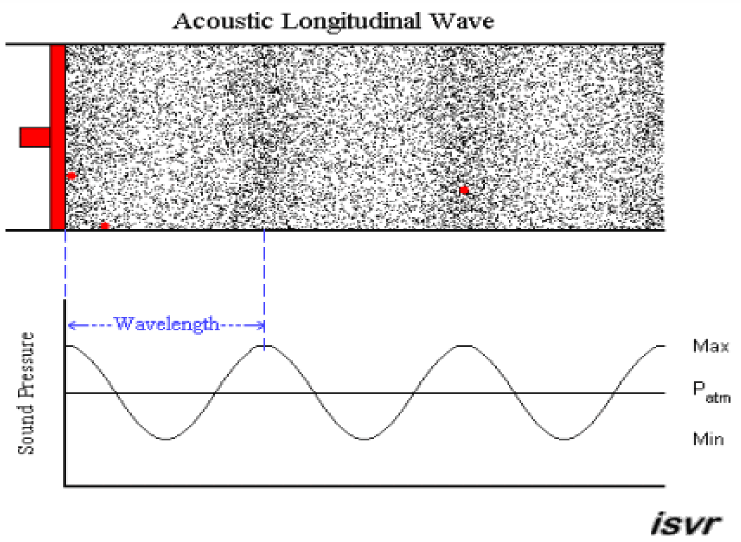
KTH VETENSKAP OCH KONST

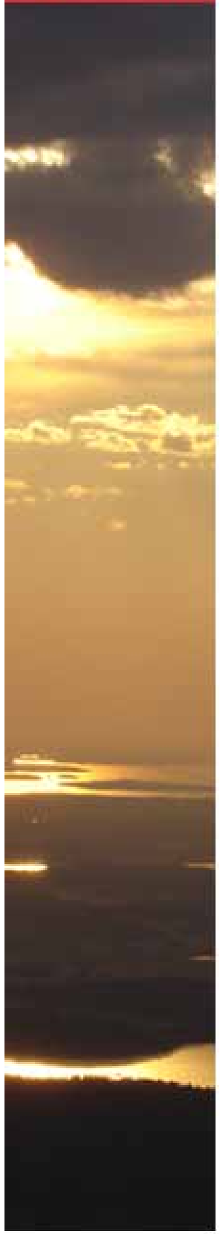
Presentation outline

- Some basic concepts
- Sound generation from windturbines
- Sound propagation in the atmosphere
- Masking by wind induced noise
- Measurements at Kalmarsund
- Summary and Conclusions

Some basic concepts

- Sound is elastic waves in gases, liquids or solids
- The waves represent small oscillations around an equilibrium, e.g., in the atmosphere around the equilibrium pressure 100 kPa.



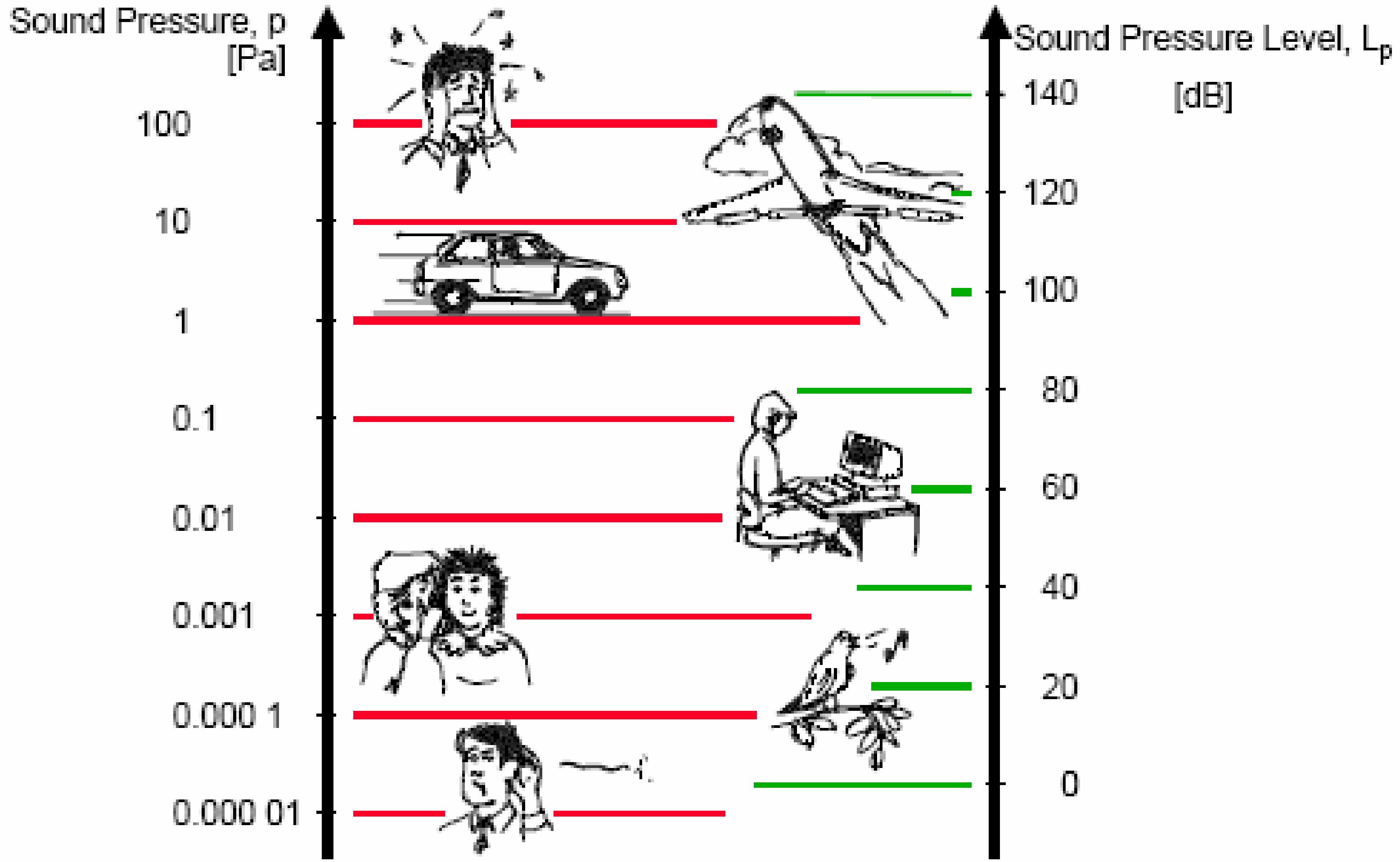


- The human ear will detect sound in the frequency range 20-20 kHz
- The smallest level a human ear can detect is around 20 μPa and the highest around 100 Pa
- To better relate sound pressures *p* to the human reponse a logarithmic scale is used

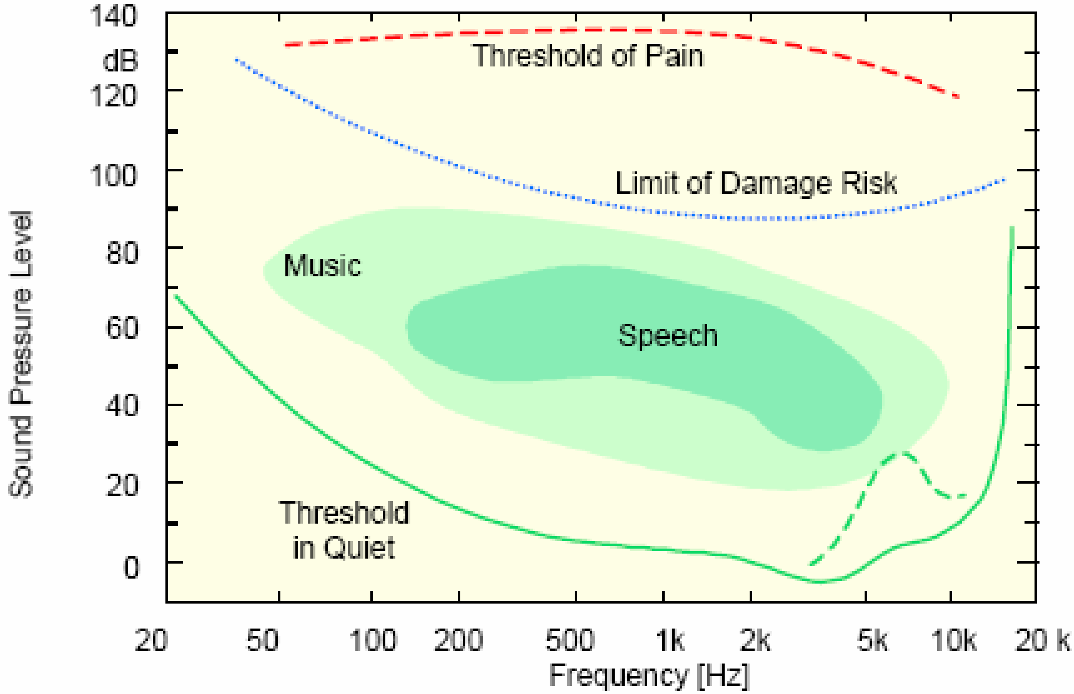
$$L_p = 10 \cdot \log \frac{\tilde{p}^2}{p_{ref}^2}, \text{[dB]}$$

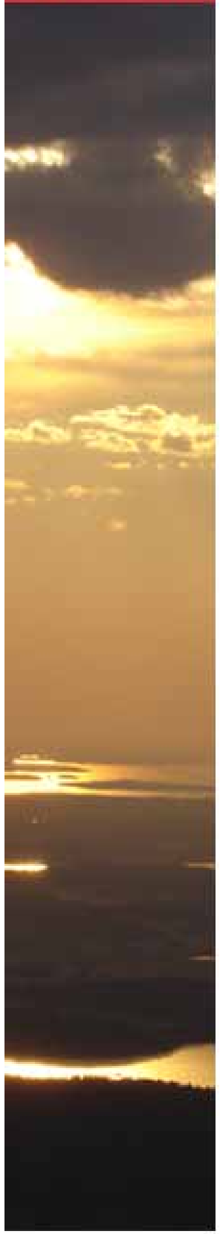
where p_{ref} is 2×10^{-5} Pa

Range of Sound Pressure Levels



- The human ear has a sensitivity that varies with both frequency and amplitude.
- This is handled by using various weighting filters A-, B- and C- when sound is measured





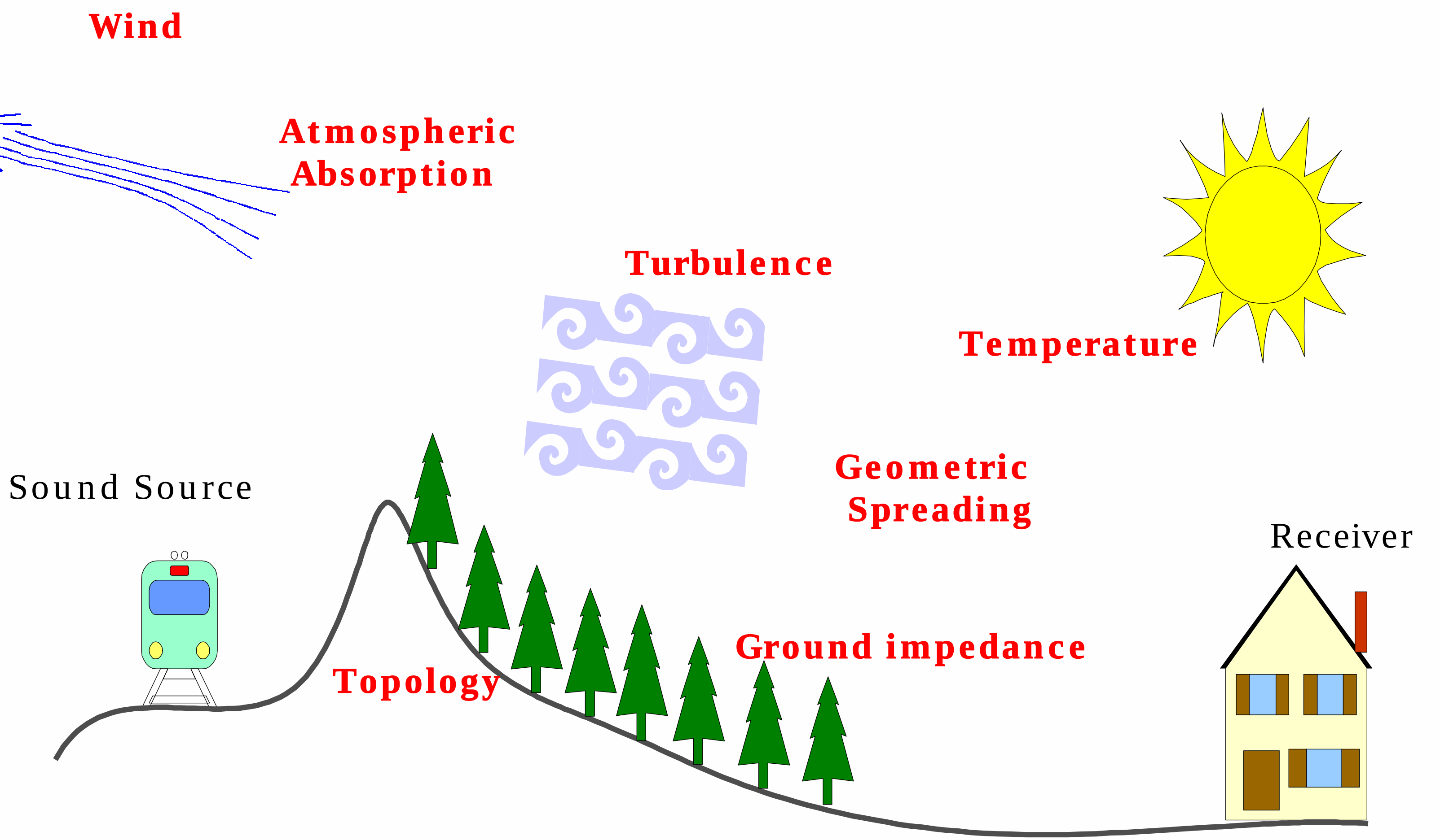
- *NOISE* - is unwanted sound that is disturbing or annoying
- Noise always involves a subjective assessment of the sound since everyone responds differently to sounds
- The most common measure to describe noise exposure is dB(A)
- For wind turbines the allowed average level is 40 dB(A)

Sound generation from wind turbines

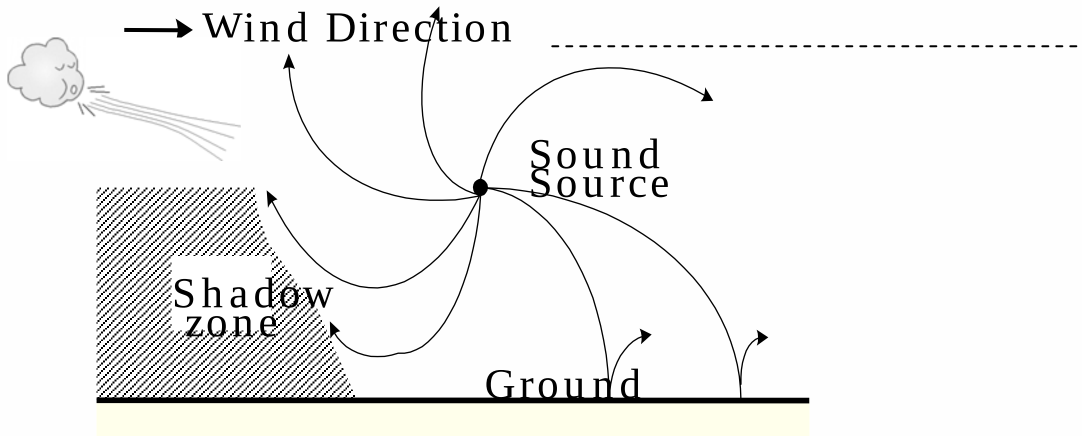
- Noise can be created from gear boxes and the blades (aerodynamic)
- It is the unsteady aerodynamic forces on the blades that create sound

- The aerodynamic sound has two parts: a tonal part (f0 < 20 Hz) and a broadband part
- At short distances (< 0.5 km) amplitude modulation due to wind gradients can occur

Sound propagation in the atmosphere

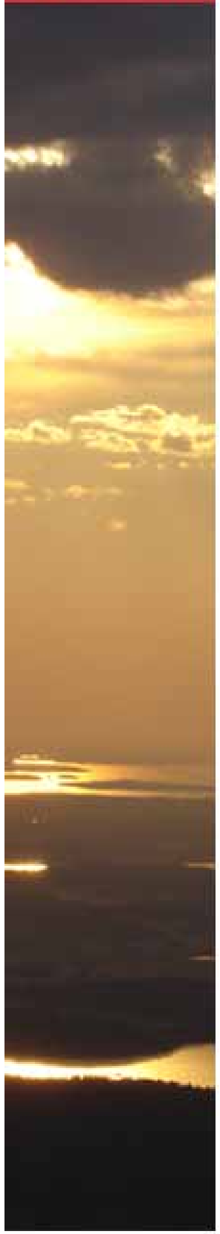


- Sound is always transmitted better in the down wind direction



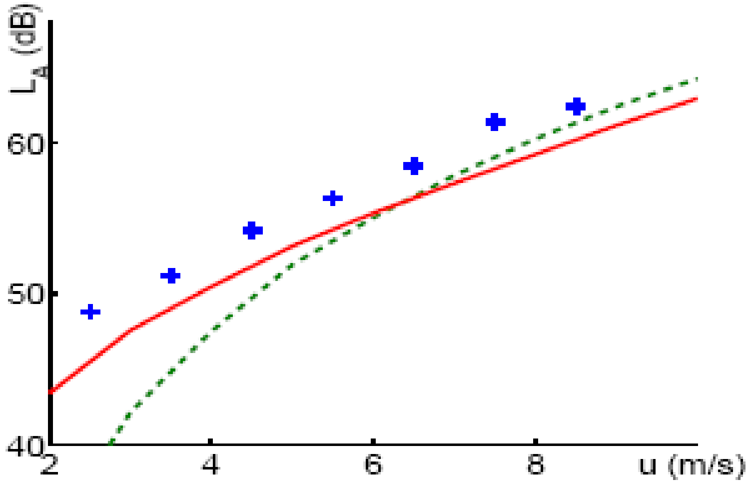
- Instead of spherical wave (3D) spreading this leads to a cylindrical (2D) type of spreading
- Cylindrical spreading gives a reduced damping with distance. For each dubbling of distance we only get 3 dB reduction instead of 6 dB for spherical spreading

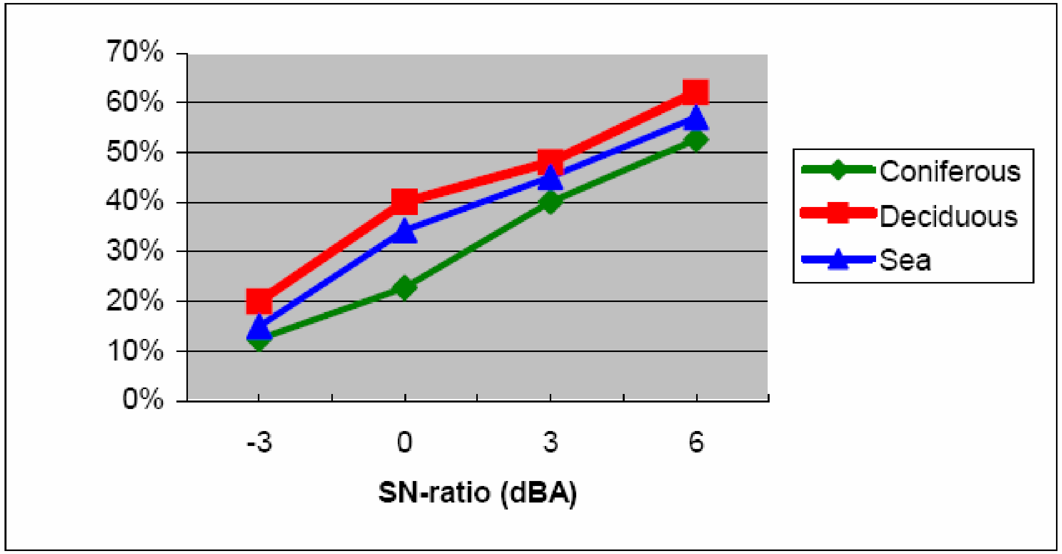
- For propagation over soft ground (”grass land”) the reflections gives an extra damping
- This added damping will on the average in the down wind restore a behaviour close to a spherical damping
- BUT for propagation over hard surfaces as the sea, rocky terrain or desserts the ground damping is small
- This is the reason why in Sweden the Environmental protection Agency has recommended (report no. 6241) the use of cylindrical spreading for distances larger than 200 m for off-shore wind turbines

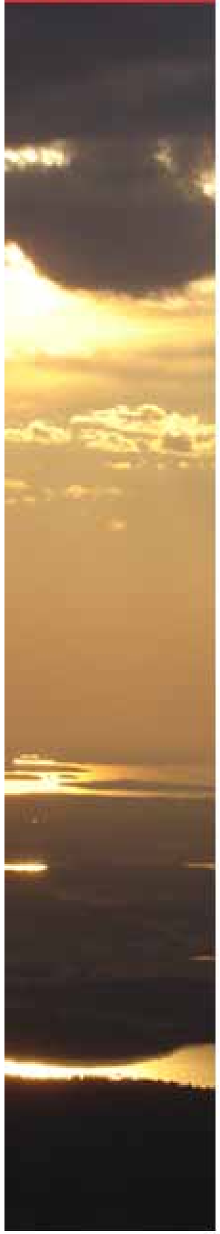


Masking by wind induced noise

- In a KTH PhD project (MASK) the masking of wind turbine noise by vegetation and sea waves are studied
- The work has resulted in a validated model for vegetation noise (Tech. Lic. thesis by Karl Bolin Nov. 2006)
- For masking it was found by Karl B that a 3 dB S/N ratio is required


L_A (dB)
60
50
40
2
4
6
8
u (m/s)


70%
60%
50%
40%
30%
20%
10%
0%
-3
0
3
6
SN-ratio (dBA)
Coniferous
Deciduous
Sea



Measurements at Kalmarsund

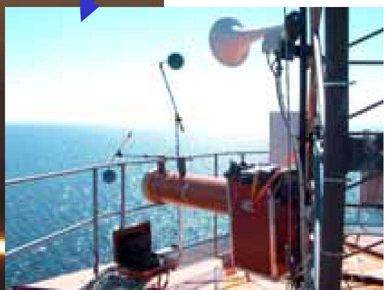
Objectives (Project TRANS)

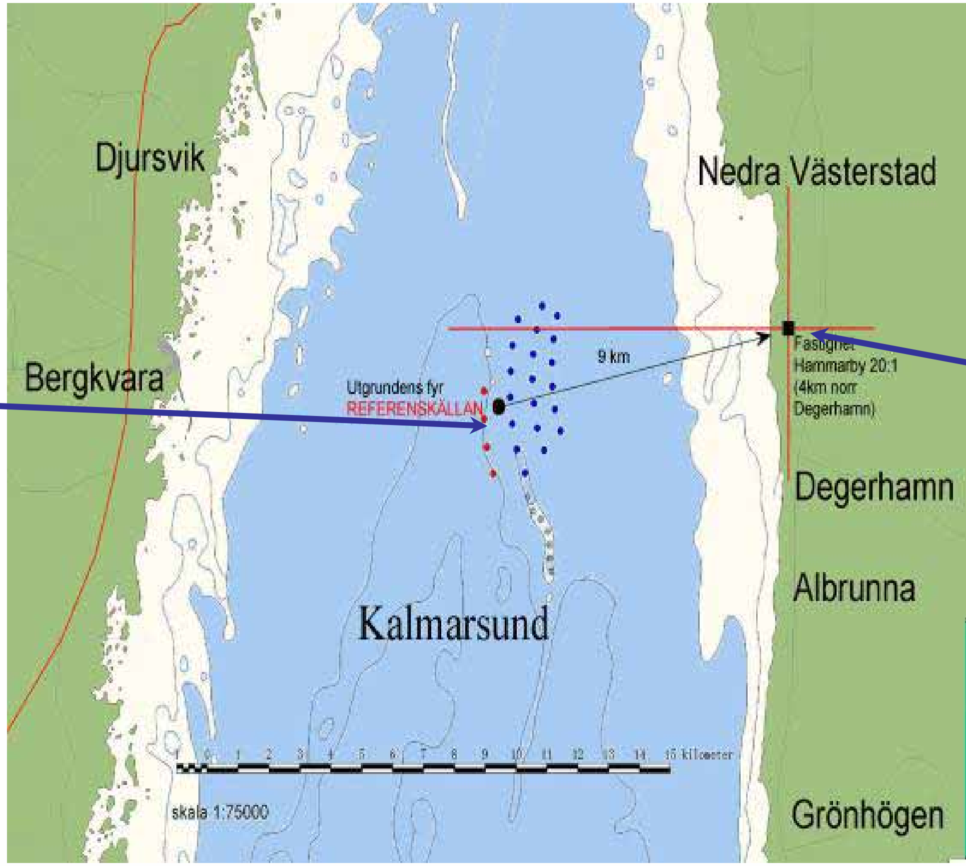
- To develop techniques for long range measurements of sound transmission
- To apply the techniques to study the occurence of cylindrical wave spreading
- To couple the occurence of cylindrical wave spreading to meteorological phenomena e.g. low level jets (LLJ)
- To test the validity of the recommendation to apply cylindrical spreading for distances larger than 200 m for off-shore wind

Measurement site and set-up

Utgrunden Light House

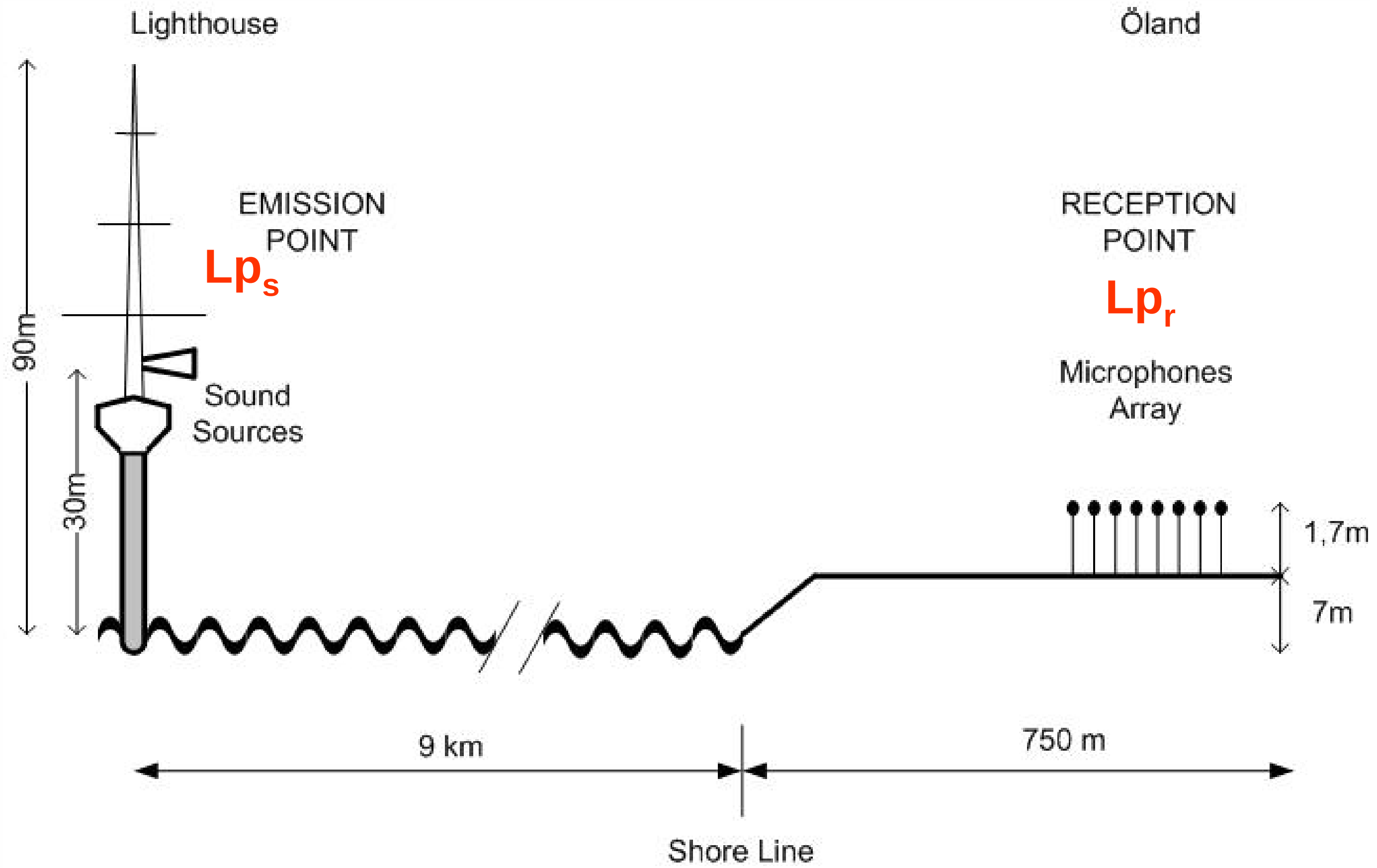
SOURCE position





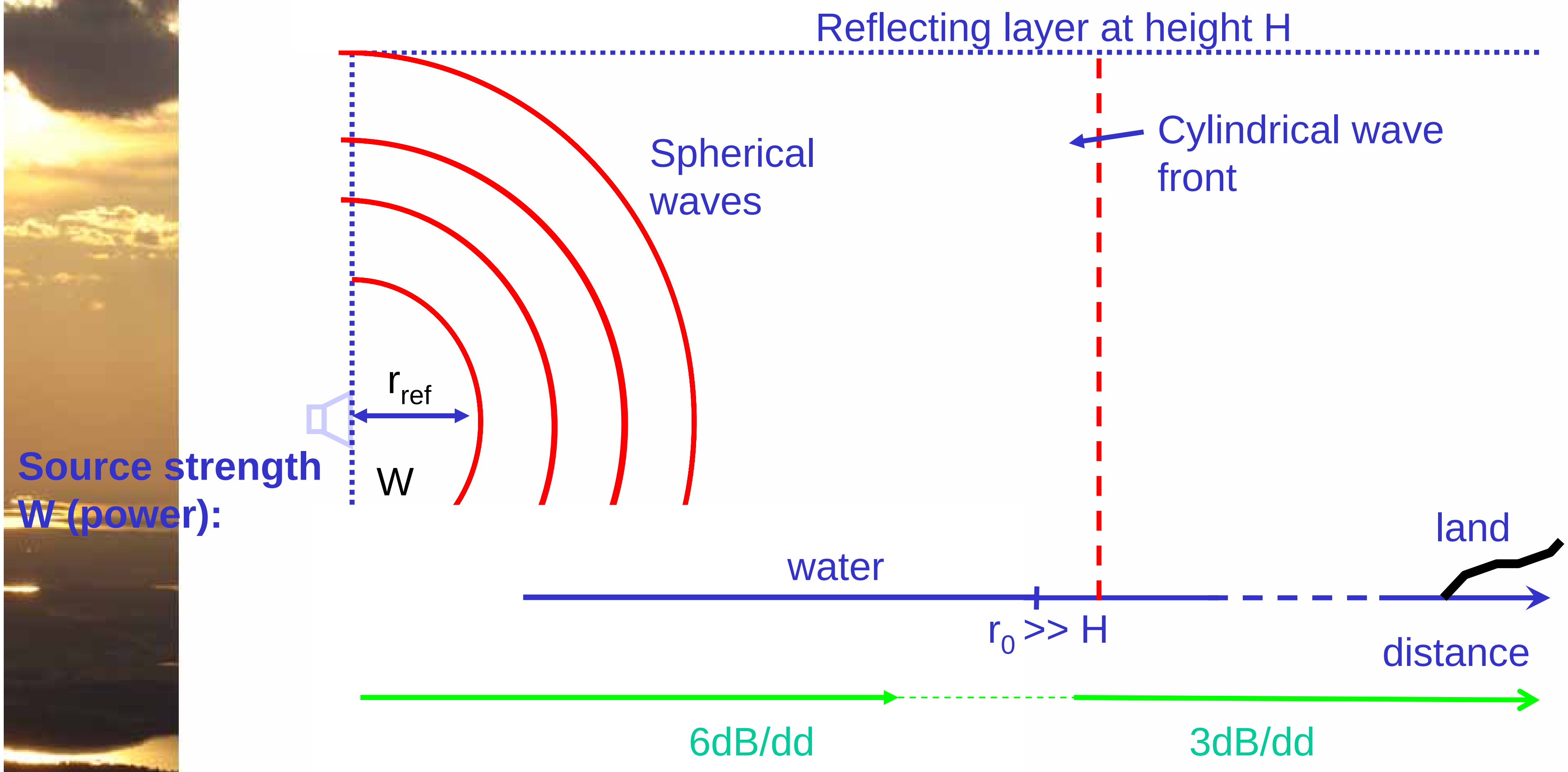
Hammarby at island Öland

RECEPTION Position with a microfone array

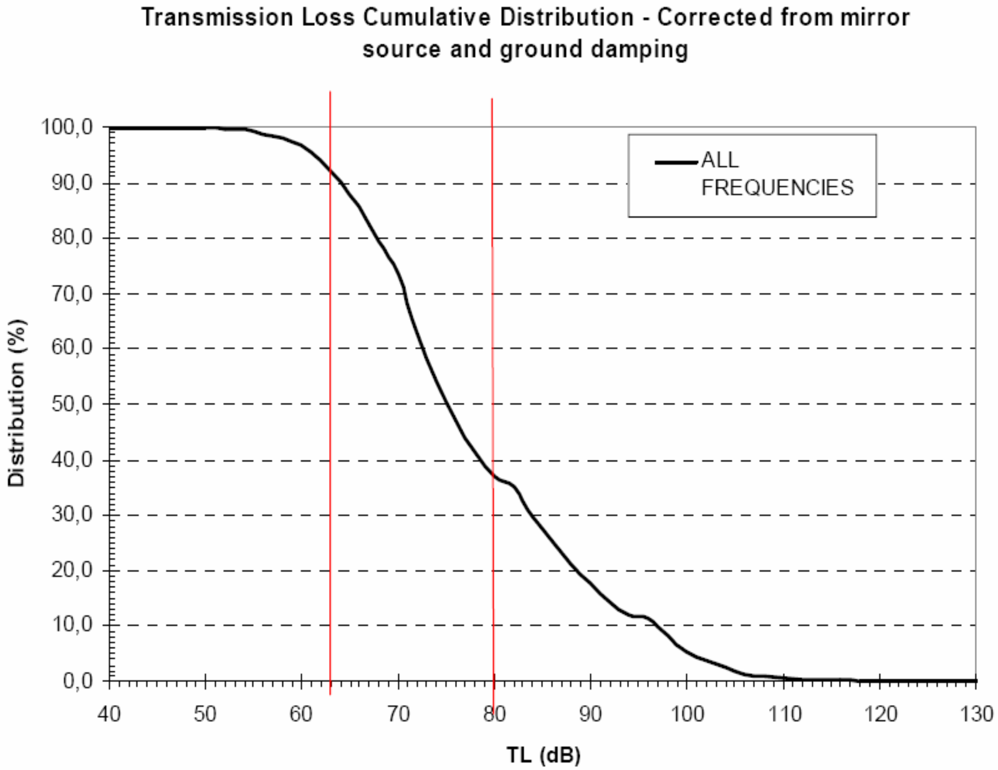


Meteorological data (wind speed/temperature/humidity) was recorded at the Lighthouse.

Transition Spherical – Cylindrical



Damping due to wave spreading based on data at 80 Hz, 200 Hz and 400 Hz



The red lines at 63 dB and 80 dB corresponds to cylindrical and spherical wave spreading respectively.

Results – Summary

Data from Utgrunden June 2005/2006	80 Hz	200 Hz	400 Hz	All frequencies
Average TL = $10\log_{10}\left(\frac{1}{N}\sum_{n}10^{-TL_n/10}\right)$ [dB]	70	67	67	68.4
TL_{10} [dB]	97	94	95	97
TL_{90} [dB]	65	62	62	64

The expected Transmission Loss with the model recommended by the Swedish Environmental Protection Agency is for this case = 63 dB. This value deviates significantly from the observed average 68 dB but is close to the TL90 value for our data.

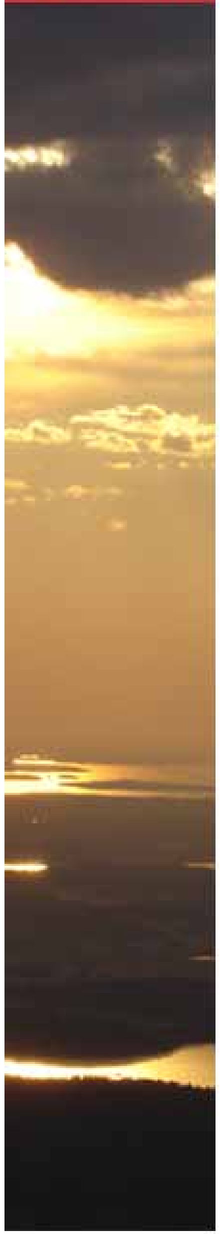
Summary and Conclusions

- Sound propagation from wind turbines is strongly affected by the meteorological conditions

- Reduced damping over areas with hard surfaces e.g. the sea can be expected. Because the ground damping occuring for soft surfaces (e.g. grass land) does not exist

- Wind induced noise from vegetation and sea waves can be effective in masking wind turbine noise (Tech. Lic thesis K. Bolin KTH 2006)

- The occurrence of cylindrical wave spreading in Kalmarsund has been investigated by KTH



- Based on data taken under June 2005/2006 it is found that cylindrical wave spreading on the average occurs after a distance of 700 meters

- This result indicates that the recommendation by the Swedish Environmental Protection Agency (report no. 6241) to apply cylindrical wave spreading after 200 meters for off-shore wind turbines is too strict