GPI RAS

Effect of random hydrodynamic inhomogeneities on low-frequency sound propagation loss in shallow water

Session: 1pAO8 (session in Honor of Stanley Flatté II)

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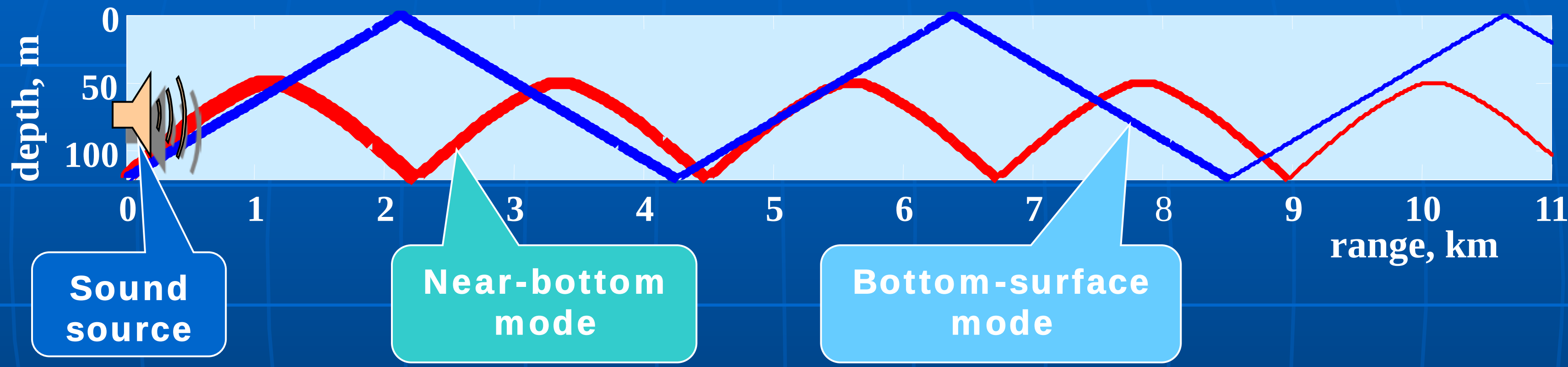
158th meeting of the ASA *26-30 October* *San Antonio, Texas*

Sound absorption in the bottom

Representation of the sound propagation
in terms of mode theory (Brillouin rays)



- at low frequencies (up to several kilohertz), the absorption coefficient in water is negligible in comparison with that in the bottom;

- during long-range propagation (dozens of kilometers), the rays suffer multiple interactions with the bottom that results in a significant energy loss.

Principal factors influencing the sound interaction with the bottom during long-range waveguide propagation

- Deterministic:
  - parameters and structure of the seabed
  - sound frequency
  - sound speed profile in the water column (summer and winter conditions)
  - source depth (mode structure)
- Random:
  - interface roughness (surface waves), inhomogeneities of the medium (internal waves)

References

- S.T. McDaniel, D.F. McCammon. Mode coupling and environmental sensitivity of shallow-water propagation loss predictions. J. Acoust. Soc. Am. 1987. V.82(1). P.217-223.
- D. Rouseff, T.E. Ewart. Effect of random sea surface and bottom roughness on propagation in shallow water. J. Acoust. Soc. Am., 1995. V.98(6). P.3397-3404.
- B.G. Katsnelson, V.M. Kuz'kin, S.A. Pereselkov, V.G. Petnikov. Sound wave attenuation in shallow water with rough boundaries. 1998. ICA/ASA Proceedings, Seattle, P.2713-2714.
- J. Xun Zhou et al. Geoacoustic parameters in a stratified sea bottom from shallow-water acoustic propagation. J. Acoust. Soc. Am. 1987. V.82(6). P.2068–2074.

Problem statement

Problem:

Effect of random surface and internal waves on the average long-range low-frequency sound propagation loss in typical shallow water acoustic waveguides (the Barents Sea and the US Atlantic Shelf), in different seasons.

The sound field amplitude is averaged over both the waveguide depth and the interval of interference beating, and over ten independent realizations of random inhomogeneity as well.

Instrument:

Numerical simulations using mode theory.

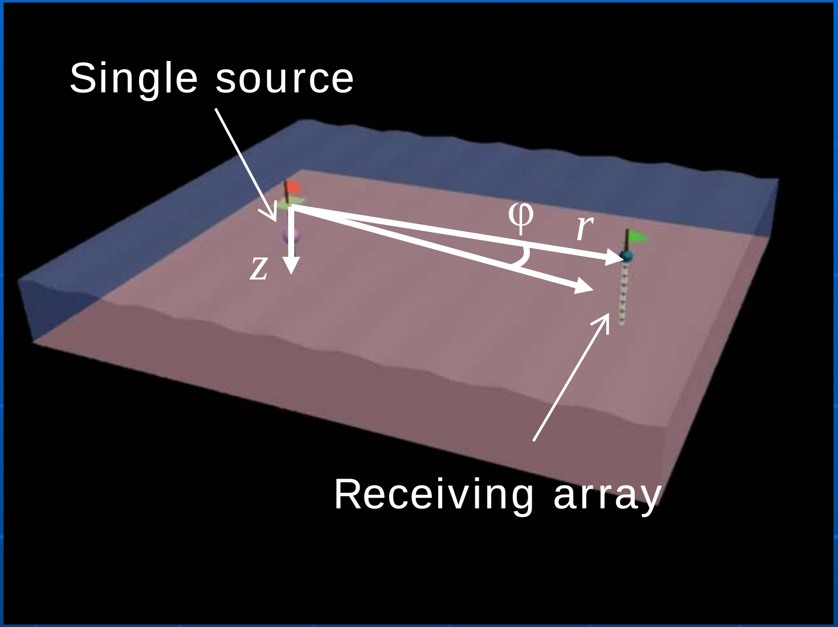
Purpose:

Should we take into account random surface and internal waves while estimating energy characteristics of a hydroacoustic system or evaluating the effective bottom parameters?

Basic relations

(1) $$P(r,\varphi,f) = \frac{1}{H}\int_0^H \sqrt{\sum_m^M \left|p_m(r,\varphi,z,f)\right|^2} dz$$

(2) $$B(r,\varphi,f) = 20\lg\frac{P(r,\varphi,f)}{P(r_{in},\varphi,f)} + 10\lg\frac{r}{r_{in}}$$



where r_{in} is the initial range [km],

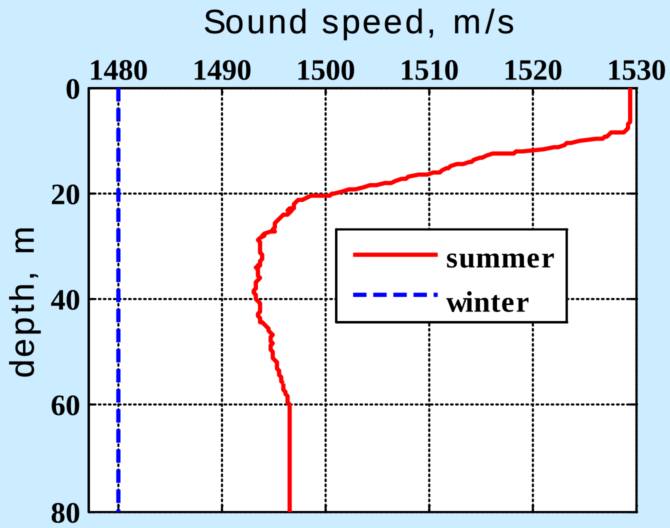
H is the waveguide depth [m],

p_m is the m-th mode amplitude [Pa] at the frequency f

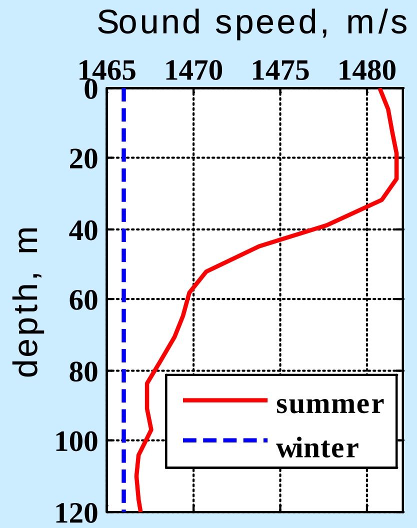
(3) $\beta(r) = dB/dr$ is the local sound attenuation coefficient [dB/km]

Initial data for numerical simulations

The US Atlantic Shelf



The Barents Sea



Seabed parameters:	
sound speed	1600 m/s
density	1800 kg/m^3
absorption coefficient	$1.07*10^{-4}f^{1.6}$ dB/km/Hz
Frequency band	100 to 500 Hz
Range interval	1 to 150 km

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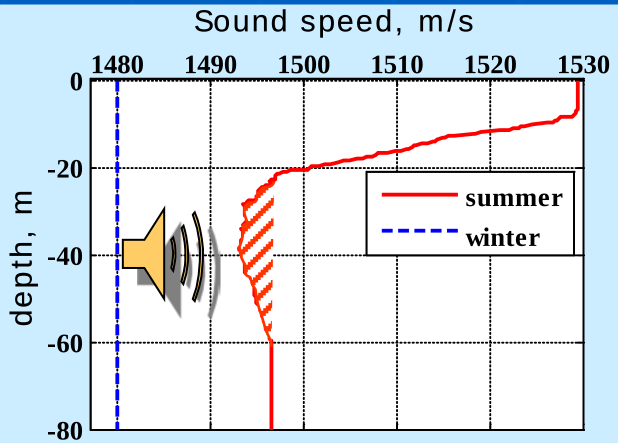
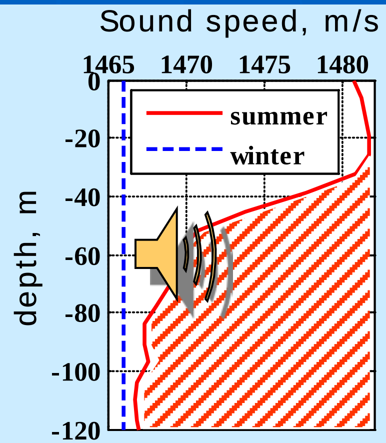
Sound speed profile in the water column

The US Atlantic Shelf

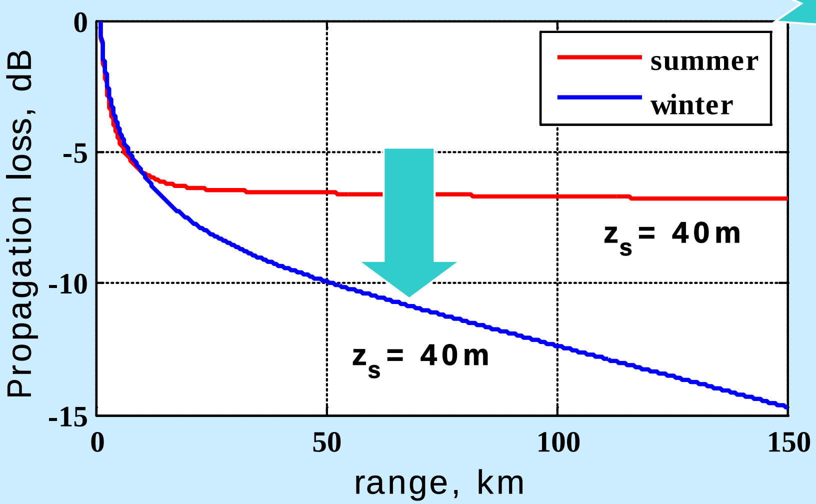


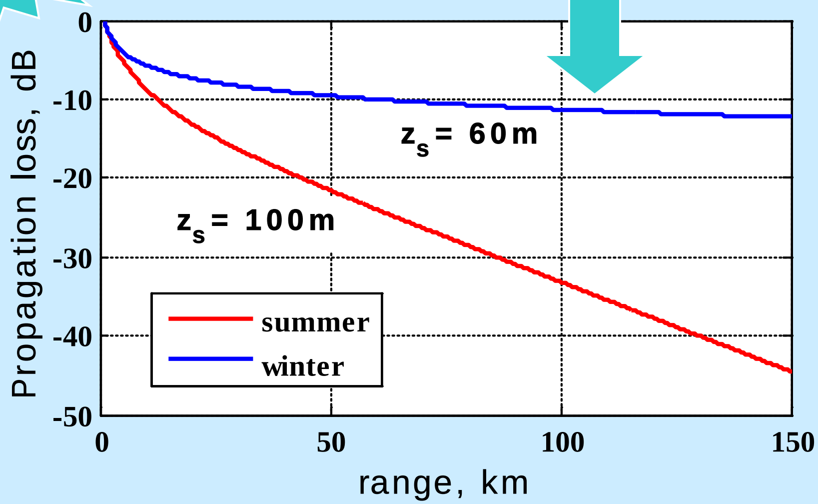
The Barents Sea



Sound source at the depth of the first mode maximum

500Hz





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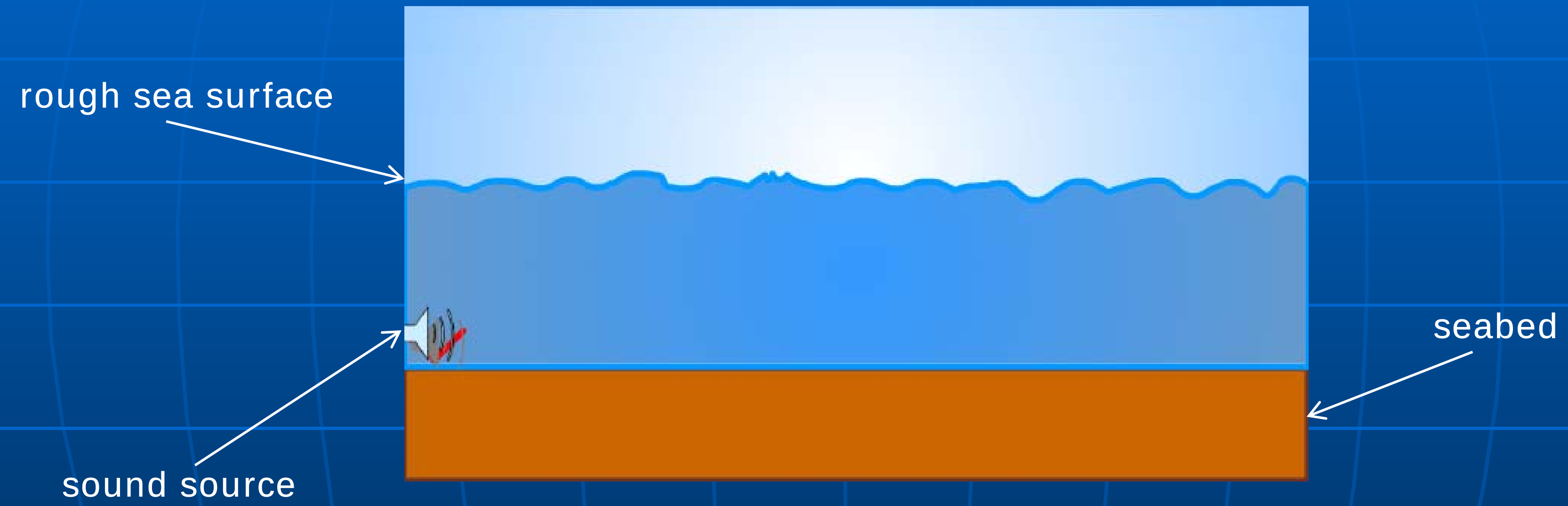
Wind-driven surface gravity waves

Ray propagation in a shallow waveguide in the presence of surface waves



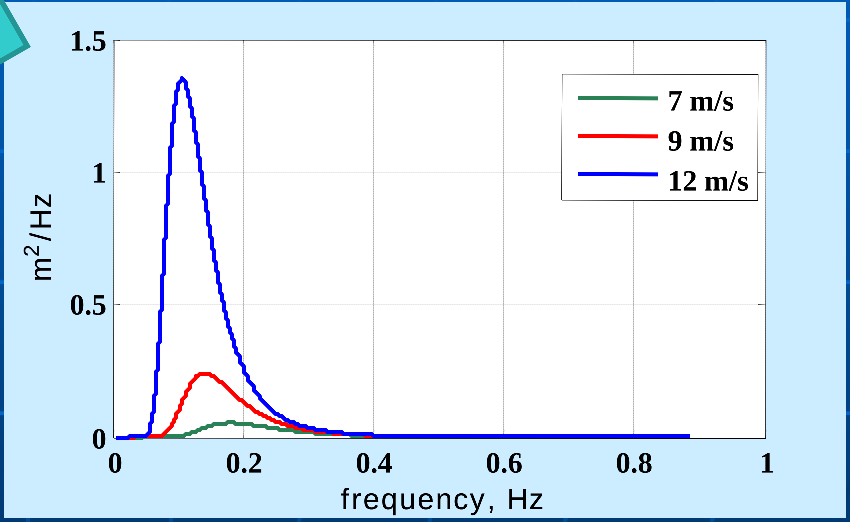
- surface waves modeling is conducted using the Pierson-Neumann spectrum;
- for 12 m/s wind speed, the rms of the surface roughness is 1.2 m

Surface waves spectrum

$$S(\Omega) = 2.4\Omega^{-6} \exp\left[-2\left(\frac{g}{\Omega v}\right)^2\right]$$

Frequency spectrum (Pierson-Neumann)

gravitational acceleration wind speed



$$\Omega = \sqrt{g\tilde{k}}$$

Dispersion relation

wave number of the surface wave

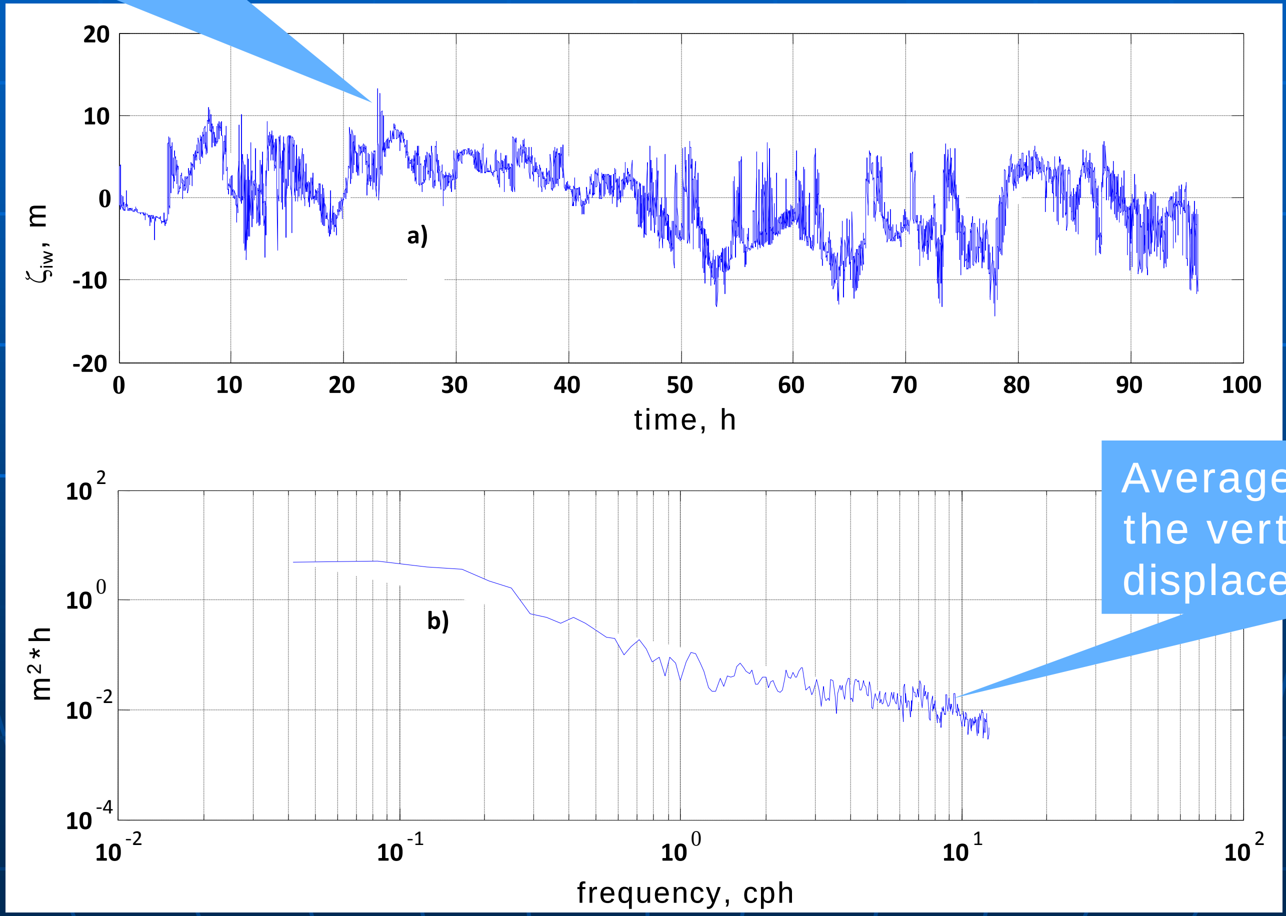
$$Q(\tilde{k}, \varphi) = \frac{g^{1/2} S(\sqrt{g\tilde{k}})}{2\tilde{k}^{3/2}} \cos^2 \varphi$$

Spatial spectrum

wind direction (we assume φ=0)

Internal waves in Shallow Water'06 experiment

Thermocline vertical displacements in SW'06

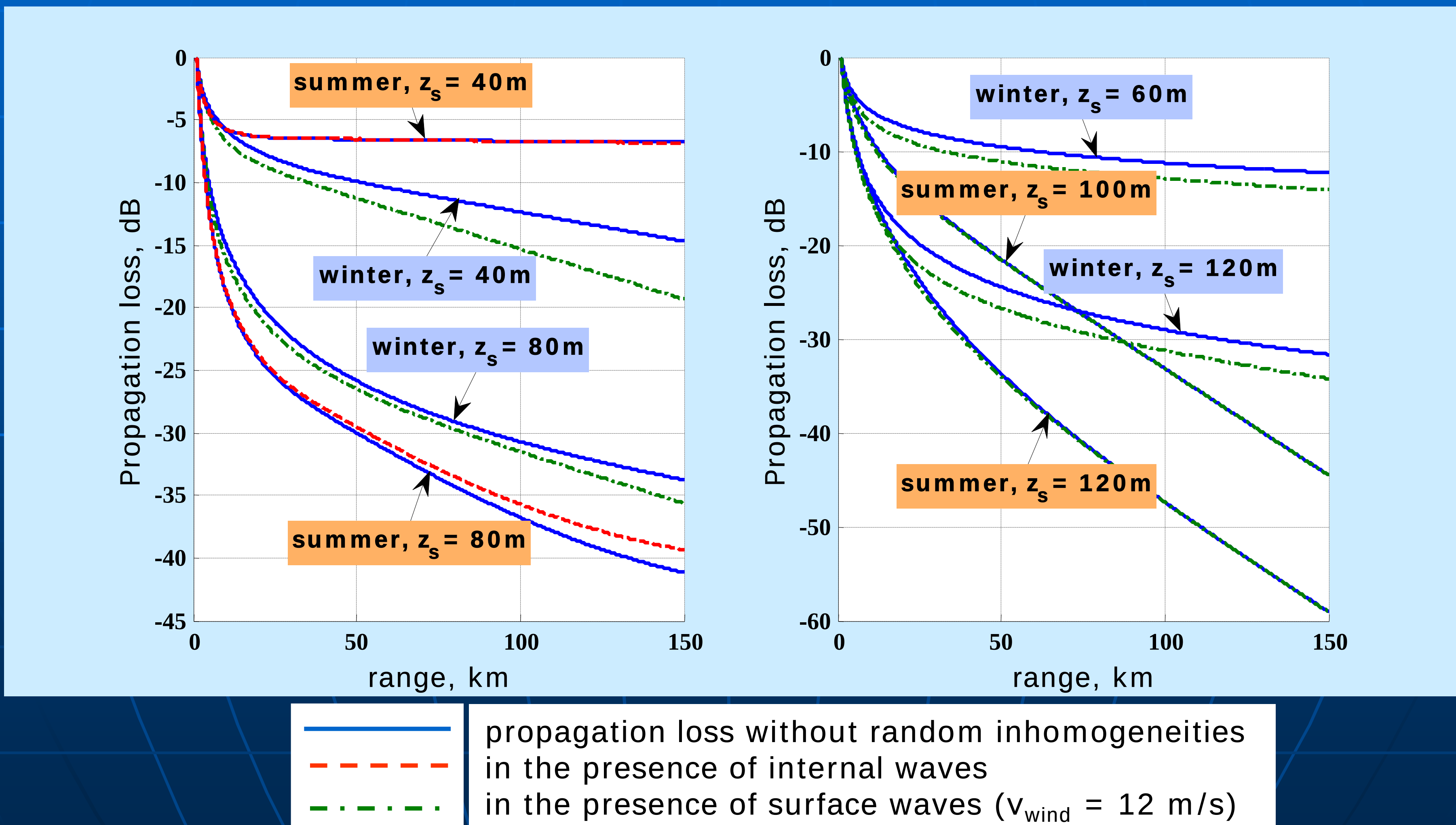


Average spectrum of the vertical displacements

Effect of random internal and surface waves on 500-Hz sound propagation loss

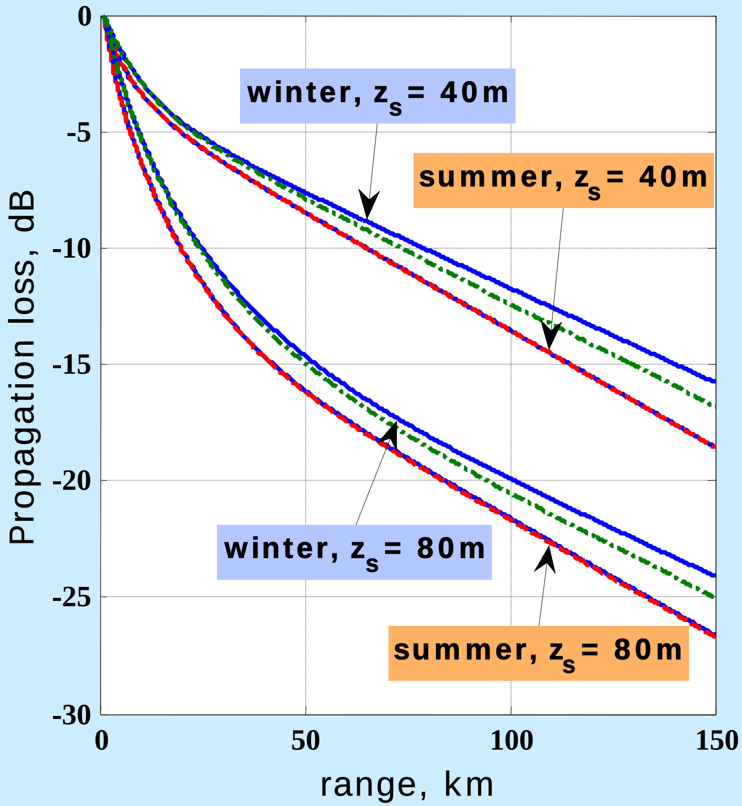
The US Atlantic shelf

The Barents Sea

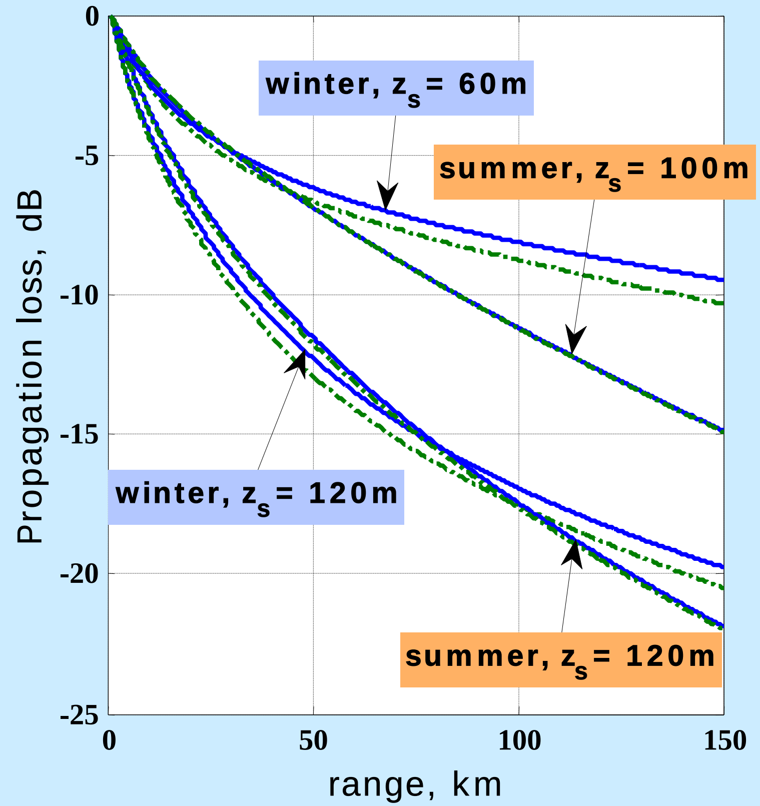


Effect of random internal and surface waves on 100-Hz sound propagation loss

The US Atlantic shelf



The Barents Sea



propagation loss without random inhomogeneities
in the presence of internal waves
in the presence of surface waves (v_{wind} = 12 m/s)

Summary

We obtain the following trends for average sound field in the presence of surface and internal waves:

- Effect of random hydrodynamic inhomogeneities on sound propagation loss becomes more pronounced with frequency increase.

- Wind-driven surface waves strongly affect sound propagation in winter conditions (e.g., for 500-Hz frequency, 12 m/s wind speed, and 150 km range, average intensity of the sound field is three times less than that in an unperturbed waveguide).

- Internal waves have a weaker effect on propagation loss than surface waves. Of specific interest, one can obtain a situation where internal waves reduce propagation loss.