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The effect of water temperature and salinity on echo sounder measurements

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1 The sound speed

Acoustic measurements are performed at many different places and at different times around the year. The water temperature and the water salinity vary, and with this the characteristics of the echo sounder transducer. How does this affect the accuracy of split-beam target strength measurement and biomass abundance estimation? The speed of sound is the fundamental parameter here, and both temperature and salinity have influence on the speed of sound (Del Grosso 1972).

2 Important transducer parameters

In Simrad Scientific Sounders, EK500, EY500 and EK60, there are a number of transducer parameters, which can be entered. Four of these are important for the discussion here:

Angle sensitivity,	n
Beamwidth,	u
Transducer gain,	g
Two way beam angle,	ψ

Simrad has specified default values for each transducer type. The default values are based upon transducer measurements in our water tank with fresh water at the temperature 18 degrees Celsius. The sound speed is here c_o =1476 m/s.

The default values are named n_o , u_o , g_o and ψ_o .
In the sea, the sound speed varies, and consequently the transducer parameters vary.

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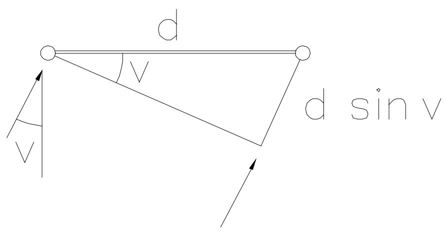
2.1 Angle sensitivity

We are looking for the first order effect only, and the angle measurement in one plane is simplified to a measurement of the phase difference between the signals received on the centre points of the transducer halves.

d is the distance between the centre points
φ is the measured phase difference
v is direction of the incoming waves (angle from the beam axis)
f is the frequency
λ is the wavelength
$c = \lambda f$ is the sound speed in the water in front of the transducer



$$\varphi = \frac{2\pi}{\lambda} d \sin v = \frac{2\pi f}{c} d \sin v$$

For small angles, this formula may be approximated to

$$\varphi = \frac{2\pi f d}{c} v$$

The coefficient in front of v is called the angle sensitivity, n. It is the ratio between the measured phase angle and the geometrical angle to the fish.

$$n = \frac{2\pi f d}{c} = \frac{2\pi f d}{c_o} \cdot \frac{c_o}{c} = n_o \frac{c_o}{c}$$

2.2 Beamwidth

For a transducer where the active area is circular and has a diameter D, the beamwidth (in radians) is approximately

$$u = \frac{\lambda}{D} = \frac{c}{Df} = \frac{c_o}{Df} \cdot \frac{c}{c_o} = u_o \cdot \frac{c}{c_o}$$

2.3 Transducer gain

If the transducer has
an active area A
and an electro-acoustic efficiency η
then the transducer gain can be written as

$$g = \eta \cdot \frac{4\pi A}{\lambda^2} = \eta \cdot \frac{4\pi A f^2}{c^2} = \eta \cdot \frac{4\pi A f^2}{c_o^{\,2}} \cdot \frac{c_o^{\,2}}{c^2} = g_o \cdot \frac{c_o^{\,2}}{c^2}$$

2.4 Two way beam angle

The equivalent two-way beam angle is the solid angle of an ideal conical beam, which would produce the same echo of a randomly distributed biomass as the real transducer (MacLennan and Simmonds 1992). This equivalent ideal beam has a flat response inside the beam and zero outsides. The equivalent beam angle is related to the transducer beamwidth by

$$\psi = a \cdot u^2$$

where u is beamwidth in radians.
and a is approximately 0.00017 (Urick 1983)

The variation with sound speed will be

$$\psi = a \cdot u_o^{\,2} \frac{c^2}{c_o^{\,2}} = \psi_o \frac{c^2}{c_o^{\,2}}$$

3 Target strength measurement

3.1 Target on axis

We shall first consider the situation that the fish is on the beam axis. Linear quantities are used. They give a better physical understanding then the logarithmic dB-quantities.

σ_{bs} is the backscattering cross section of the fish (m^2)
TS=10 logσ_{bs} is the target strength (dB)
p is the transmitter power (W)

The source level, expressed by the sound intensity at a point r_o metres in front of the transducer, is

$$i_{SL} = \frac{p}{4\pi r_o^{\,2}} g \quad (W/m^2)$$

r_o is usually set to 1 m.

The echo level received at the transducer face is (H.Bodholt 1990)

$$i_E = i_{SL} \cdot \left(\frac{r_o}{r}\right)^2 \cdot \frac{\sigma_{bs}}{r^2} = \frac{pg\sigma_{bs}}{4\pi r^4}$$

$(r_o / r)^2$ represents one way geometrical spreading loss. The absorption loss is ignored here. It would disappear later, as does the spreading loss. The equation allows calculation of the fish backscattering cross section

$$\sigma_{bs} = \frac{4\pi r^4 i_E}{pg}$$

The echo sounder executes this calculation. If the default value g_o of the transducer gain is used, the measured σ_M may be different from the real σ_{bs}.

$$\sigma_M = \frac{4\pi r^4 i_E}{pg_o} = \frac{4\pi r^4 i_E}{pg}\frac{g}{g_o} = \sigma_{bs}\frac{g}{g_o} = \sigma_{bs}\frac{c_o^{\,2}}{c^2}$$

An acoustic calibration, with a metal sphere of known target strength suspended below the transducer, gives a correct value of g at the current sound speed. It is therefore recommended to perform the calibration in order to obtain a correct target strength measurement. However, a successful calibration can only be performed in a sheltered area under calm sea condition. If the sound speed during the calibration differs from the sound speed at the survey area, the transducer gain should be set according to the previous shown formula

$$g = g_o \frac{c_o^{\,2}}{c^2}$$

with g_o now being the transducer gain found during calibration, and c_0 the sound speed there.

3.2 Beam pattern compensation

The two-way beam pattern in one plane is close to the mathematical formula:

$$B = 6 \cdot \left(\frac{v}{u/2}\right)^2 \qquad \text{(dB)}$$

As shown earlier, the beamwidth varies with the sound speed, and the beam pattern varies accordingly

$$B = 6 \cdot \left(\frac{v}{u_o/2}\right)^2 \left(\frac{c_o}{c}\right)^2$$

The software in the echo sounder estimates the direction to the fish from $v = \varphi / n$ and compensates the beam pattern with the formula

$$B_M = 6 \cdot \left(\frac{\varphi / n}{u/2} \right)^2 = 6 \cdot \left(\frac{\varphi}{nu/2} \right)^2$$

The parameters n and u vary with the sound speed, and the accuracy of the target strength measurement depends on the values of n and u entered by the user. Two cases are, both leading to a correct result, are presented here:

Case I. The default values are used.
The phase angle φ is connected with the angle to the fish by the current angle sensitivity: $\varphi = nv$

$$B_M = 6 \cdot \left(\frac{nv}{n_o u_o / 2} \right)^2 = 6 \cdot \left(\frac{v}{u_o / 2} \right)^2 \left(\frac{c_o}{c} \right)^2$$

We see here that the beam pattern used for compensation varies with the sound speed exactly like the real beam pattern.

Case II. Simrad provides a PC-program “Lobe” for calibration.
It stores a great number of TS-values, when the calibration sphere is moved through the beam, and finds a best-fit value for the beamwidth. The angle sensitivity is left at its default value. The angle sensitivity is difficult to check, and since the formula for beam pattern compensation has the product nu it is not really necessary to adjust n and u separately. This means that the beamwidth obtained in “Lobe” may not be the true beamwidth, but it is calculated so that the product nu gives correct beam pattern compensation.

3.3 Example

A research vessel is equipped with Simrad EK500 Scientific Sounder and transducer ES38B. The default values for this transducer is:
n=21.9
u=7.1 degrees
g=450, G=10log$g$=26.5 dB

Calibration is performed in a sheltered bay with a sea water temperature of 10 degrees Celsius, corresponding to a sound speed of $c_o = 1490$ m/s. A transducer gain of 440 (26.4 dB) is obtained during the calibration and entered into the echo sounder. The PC-program “Lobe” shows a beamwidth of 7.2 degrees, which is also entered into the echo sounder. The angle sensitivity is left unchanged. The echo sounder is now set for accurate target strength measurements in seawater at 10 degrees Celsius.

The vessel goes to arctic seas with 0 degrees Celsius and a sound speed of $c = 1450$ m/s. It is impossible to calibrate in open sea, so a new transducer gain is calculated manually:

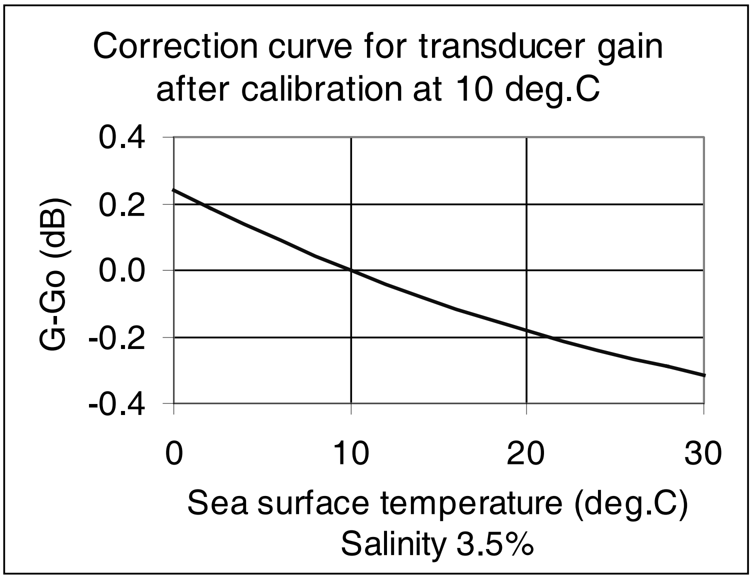
$g = g_o \frac{{c_o}^2}{c^2} = g_o \cdot \frac{1490^2}{1450^2} = g_o \cdot 1.056$, corresponding to an increase of 0.2 dB

If the transducer gain obtained during the calibration remains unchanged in the echo sounder, the measured backscattering cross section σ_M of a fish is 1.056 higher then the real cross section. The target strength is overestimated with 0.2 dB.

If the new transducer gain, 26.6 dB is entered into the echo sounder, the target strength measurements will be correct.

The angle sensitivity and the beamwidth are not changed. As shown earlier in case I, the beam pattern compensation will still be correct.

In this example an error of 0.2 dB could occur. This is not a large error, but other examples, with greater deviations in water temperature and salinity, could show larger errors. An adjustment of the transducer gain according to the current sound speed eliminates this error.



4 Volume backscattering strength

The biomass abundance is estimated from the measurement of the volume backscattering strength s_v and integration of this quantity. The measurement of s_v and how it is affected by changes in the speed of sound, is the topic of this chapter.

The echo level (sound intensity) received at the transducer face is

$$i_E = i_{SL} \cdot \frac{r_0^{\ 2}}{r^4} \cdot s_V \cdot V$$

V is the sampling volume, $V = \psi \cdot r^2 \cdot \frac{c_r \tau}{2}$

where ψ is the equivalent ideal solid beam angle of the transducer

c_r is the sound speed at the depth of the biomass

τ is the pulse duration

Simrad scientific echo sounders utilise these formulas to calculate s_V.

$$s_V = \frac{i_E}{i_{SL}} \cdot \frac{r^2}{r_0^{\ 2}} \cdot \frac{1}{\psi c_r \tau / 2} = \frac{i_E 4\pi r^2}{pg\psi c_r \tau / 2}$$

If the default values g_o and ψ_o are used, the measured s_M could be expected to differ from the real s_V

$$s_M = \frac{i_E 4\pi r^2}{p_o g_o \psi_o c_r \tau / 2} \cdot \frac{g_o \psi_o}{g\psi} = s_V \frac{c^2}{c_o^{\ 2}} \frac{c_o^{\ 2}}{c^2} = s_V$$

but luckily, the variations in g and ψ cancel each other.

5 Other transducer parameters

The variations of n, u, g and ψ discussed above, are caused by the law of physics and are therefore common for all transducers. In addition each transducer type may show changes in impedance and sensitivity, when the temperature changes.

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