Multi-static, multi-frequency scattering from zooplankton

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Abstract: Inversion of multi-frequency acoustic backscattering can be used to estimate size-abundances of zooplankton, given a valid model for backscattering for the zooplankters. The physical properties of the scatterers, density and compressibility (or compressional-wave sound speed), are usually assigned fixed values in the scattering model. These properties would be of interest if they could be measured *in situ*, e.g. to examine changes in lipid contents over seasons. Extension of currently-favored backscattering models to multi-static configurations looks promising as a method to directly measure these relevant physical properties simultaneously with size-abundance estimation.

Methods for estimating size-abundances of small zooplankton such as copepods from inversion of multi-frequency backscattering measurements have existed for many years (1,2). Application of this method to copepod-like zooplankton has become almost routine in many situations (3,4).

The model used for oceanic scatterers such as copepods comprises the first two terms of the Anderson fluid sphere model (2,5), the monopole and dipole modes. Zooplankton such as copepods are definitely non-spherical scatterers, however laboratory measurements of target strengths (6) do clearly suggest the assumption of fluid properties is warranted. The rationale behind creating this model was the assumption that weak, physically-compact scatterers with irregular shapes should certainly exhibit volumetric expansion/contraction (monopole mode) and displacement in the direction of the source wave (dipole mode) but would not likely support any purely geometric modes. Validation of this model was done by comparing acoustically-estimated size-abundances to pump samples taken simultaneously (2).

The complete model is multi-static, however, and inclusion of angle dependence in the truncated model is trivial. The complete bistatic model has been verified for large ka using fluid-filled, neoprene latex balloons (7). Given the success of the truncated model in backscattering, it seems likely that this model should serve--at least as a first approximation--for bistatic scattering as well.

Previous work with the full model suggested the possibility for using bistatic scattering to remove the effects of density and compressibility contrasts on measurements of size for individual scatterers (8). Review of this work also leads to a somewhat contradictory conclusion: that measurements at several angles might allow one to estimate the fluid properties as well as size for a fluid scatterer. In fact, modeling of the behavior of bistatic scattering shows that the spectra of scattering are sensitive to changes in physical properties. Figure 1 illustrates
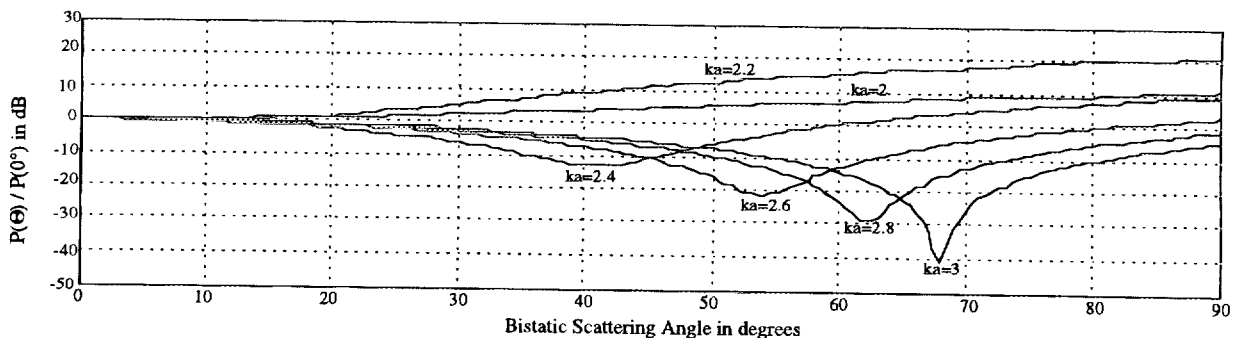

FIGURE 1. Predicted scattering from a truncated fluid sphere, normalized by the backscattering level, versus bistatic angle. The material properties are fixed: the density ratio, g=1.03, and the sound speed contrast, h=1.04. The wavenumber-radius product, ka, ranges from 2 to 3. As in the case of backscattering, since several of the curves intersect there are no unique single-angle/single-frequency solutions for scatterer size.

that angle diversity is an analog for frequency diversity for these scatterers. This establishes the (predicted) validity of bistatic measurements for size estimation.

One of the curves of Fig. 1 (ka=3) is shown in more detail in Fig. 2 for two values of sound speed contrast differing by 1%. Inspection of this figure suggests that bistatic scattering also appears to be amply sensitive to changes in the physical properties, sufficiently to warrant experimental investigation of multi-frequency, bistatic scattering for *in situ* estimations of the physical properties of zooplankton.
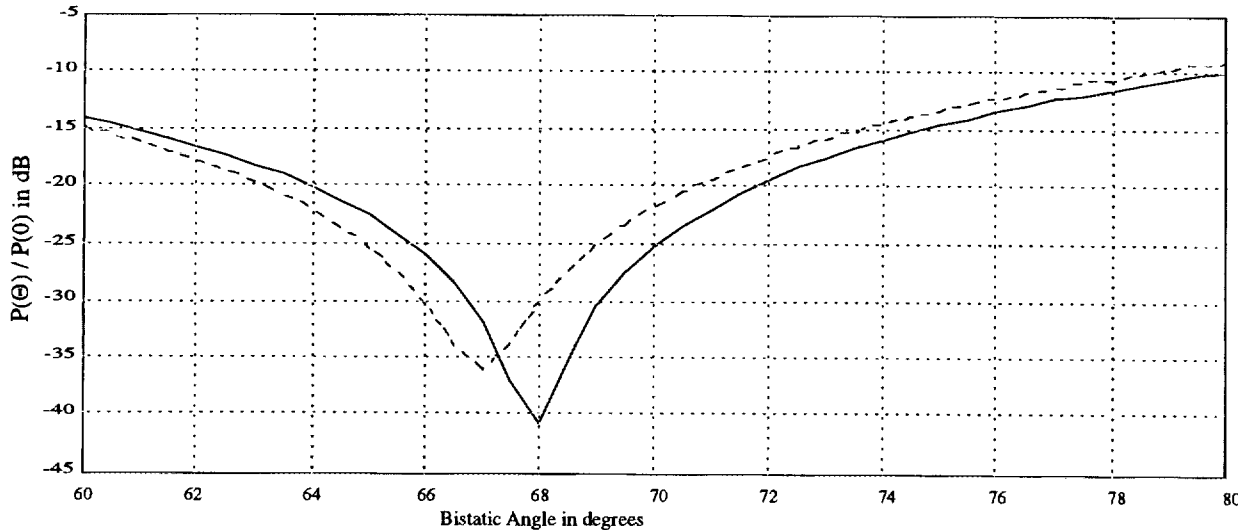

FIGURE 2. Detail of predicted bistatic scattering from a truncated fluid sphere with ka=3 and density contrast, $g = 1.03$, for two values of sound speed contrast, h=1.04 (solid line) and h=1.05 (dashed line). Relative scattering can change by as much as 11 dB for a 1% change in h at fixed angle. The minimum in the scattering curve also moves by about $1°$ in azimuth.

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